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THESIS

DESIGN AND ANALYSIS OF A GENERALIZED CLASS OF FIN-LINE FILTERS

by
Keith B. Alexander
and
Steven R. Hamel

September 1983

Thesis Advisors: Yi-Chi Shih
E. A. Milne

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Design and Analysis of a Generalized Class of Fin-Line Filters

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requirements for the degree of

MASTER OF SCIENCE IN SYSTEMS TECHNOLOGY (ELECTRONIC WARFARE)

and

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from the

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I. INTRODUCTION

Integrated circuits for use below about 3 GHz demonstrate clear advantages in terms of size, weight, cost and electrical performance, over alternative techniques. These advantages often accrue as a result of component miniaturization. However, as the frequency is increased to the centimeter and millimeter regimes, the resultant excessive miniaturization creates problems associated with critical mechanical tolerances, and questionable production uniformity. Moreover, concomitant undesireable electrical performance involving radiation loss, spurious coupling, dispersion and higher order mode propagation becomes unacceptable [Ref. 1]. Over the last decade, integrated fin-line structures have received increased attention as attractive media for low-insertion loss design applications which avoid excessive miniaturization, yet offer the potential for low-cost batch-processed production techniques.

The fin-line filter structure consists simply of conductive strips, or fins, which bridge the broad walls of a rectangular waveguide. That is, for waveguide operated in a TE_{mo} mode, the conducting fins are suspended in the E-plane. Metal sheet structures suspended in the center of the waveguide (herein referred to as "Class I" structures) offer the simplest possible structure for analysis and

design. These unilateral center-line fins present fabrication and suspension difficulties. Bilateral fin-line filters may be constructed as printed circuits on low-loss dielectric substrates and inserted in the center of the guide. These ("Class II") filters offer the advantage of construction by well developed printed circuit techniques, and relatively straight forward analysis [Refs. 2, 3], but still present the problem of mechanically fixing the fin-line structure in the center of the guide. Clearly, fin-line structures printed on dielectric substrate and affixed to the waveguide sidewalls ("Class III" structures) offer mechanical advantages over the other two class types. The authors know of no previous investigations concerning Class III strucutres.

The purpose of this thesis study was to develop and validate a computer aided design (CAD) program for the design and analysis of all three class types of E-plane fin-line filters. To this end, the appropriate mathematical expressions were derived for a generalized fin-line structure.

The generalized structure has two different dielectric materials in the guide. The Class II filter described above corresponds to the case where the higher dielectric constant material is in the center of the guide. The Class III filter has the higher permittivity material along the waveguide walls. The generalized Class I filter has the same permittivity throughout the fin-line structure.

The derived transcendental equations relating the mode wave number values in different zones of the waveguide apply to all class types. However, when the difference in dielectric constants is large the trigonometric functions in the transcendental relationship may become hyperbolic. Moreover, Class II and Class III structures require different but equivalent expressions in the numerical analysis to avoid singularity occurances.

The analysis method employed is a mode-matching technique uniquely applied to include the effects due to an arbitrary number of higher order modes. A convergence dependence analysis assures the most efficient regional distribution of the limited number of higher order modes retained for the numerical analysis.

Validation of the complete computer program for Class I and II filters was initially conducted by analyzing k_u and k_a band fin-line filters designed and constructed by Shih [Ref. 2], and Arndt, et al [Ref. 3]. Finally, several Class I and Class III filters were designed, constructed and tested locally. These test filters were resonant in X-band (8-12 GHz) to match available test hardware.

II. THEORY

For the types of fin-line structures in waveguides considered here, each geometrical discontinuity may be considered in two distinct coordinate frames. It is useful, therefore, to expand the unknown fields in both regions in terms of their associated normal modes. Field continuity requirements are then imposed on the modes at the interface of the regions. Finally, the orthogonality property of the normal modes is used to derive an infinite set of linear simultaneous equations for the unknown modal coefficients. This is the essence of the mode-matching technique for the solution of boundary value problems [Ref. 4]. Moreover, this procedure leads directly to the scattering matrix for the discontinuity. Since the fin-line is a series of such discontinuities separated by transmission line sections, a cascading technique may be employed to develop an equivalent scattering matrix for the entire structure.

In principle, the effects of all the possible modes upon each of the others is inherently included, and the analysis is exact. In practice, the number of modes considered must be limited to a reasonably finite set. Accurate and efficient convergence of the subsequent numerical calculations is achieved by following the guidelines suggested by the studies of Shih and Gray [Ref. 5].

The derivation of the equivalent scattering matrix for the generalized fin-line structure follows. Detailed intermediate steps of the development are contained in the appropriate appendices. The basic geometry of the E-plane fin-line is shown in Fig. II-1. It is important to note that the assumed "magnetic wall" (x=0), along which the parallel magnetic field is zero, implies TE_{mo} type (m odd) incident waveforms. The computer simulation is based upon a TE_{10} incident wave.

A. EXPRESSIONS FOR NORMAL MODES AND EIGENVALUES

By assuming incident modal electric (E) fields of the TE_{mo} type, field symmetries allow the simplified waveguide geometry shown in Fig. II-2. The conducting fin is assumed to be infinitely thin. The dielectric materials in the guide are assumed to be lossless, homogeneous, and istropic. Also, the fin-line structures and substrates must be constructed to maintain symmetry about the x = 0 plane. For simplicity of discussion, the guide is considered to be comprised of two regions, and two zones. The regions are Z dependent. Region I refers to the guide before the metal fin boundary, and Region II refers to the guide after (plus Z direction) the fin boundary. The zones are X dependent. Zone 1, sometimes called the lower zone, refers to the condition:

$$0 \leq x \leq d \quad .$$

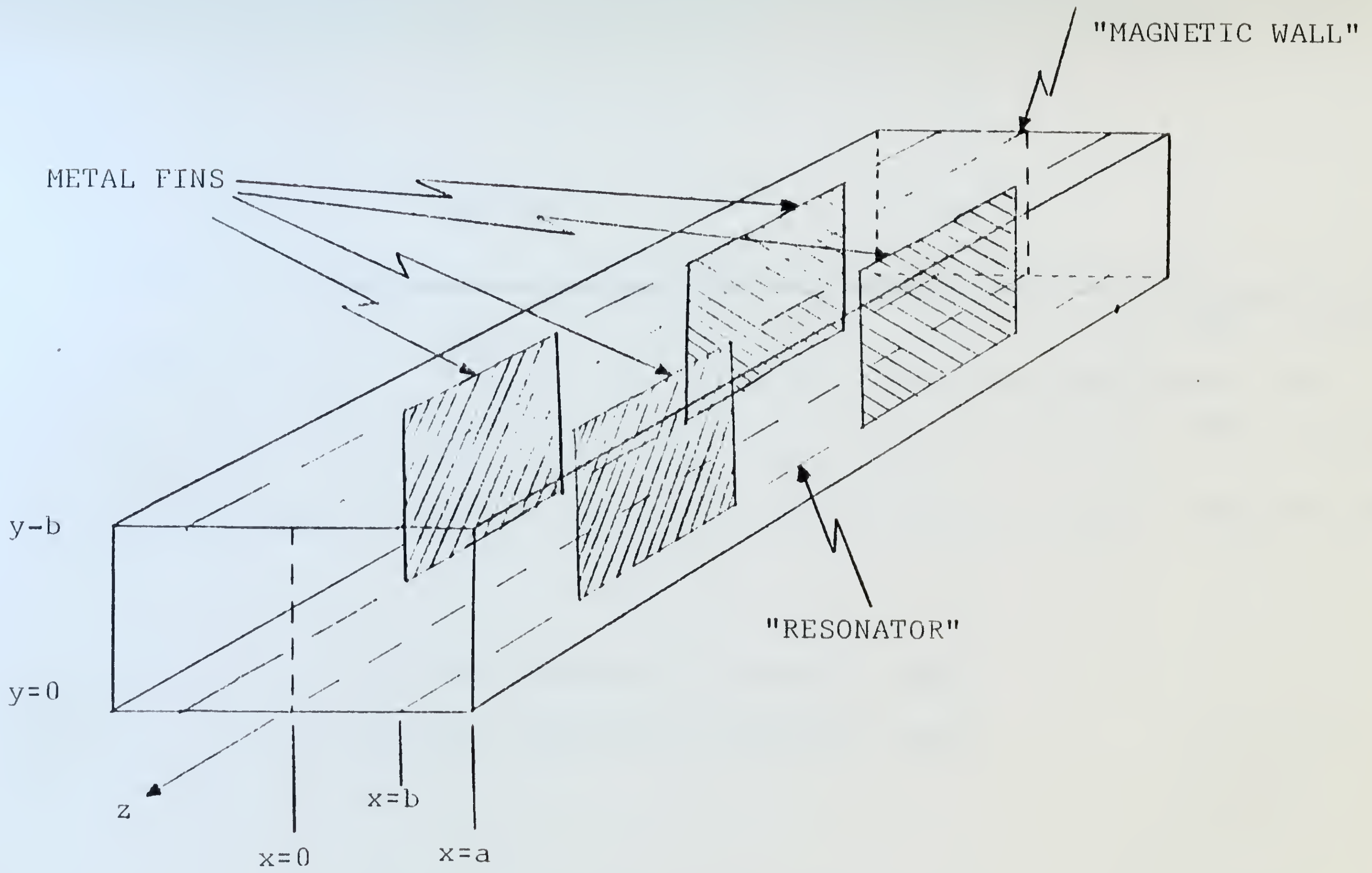
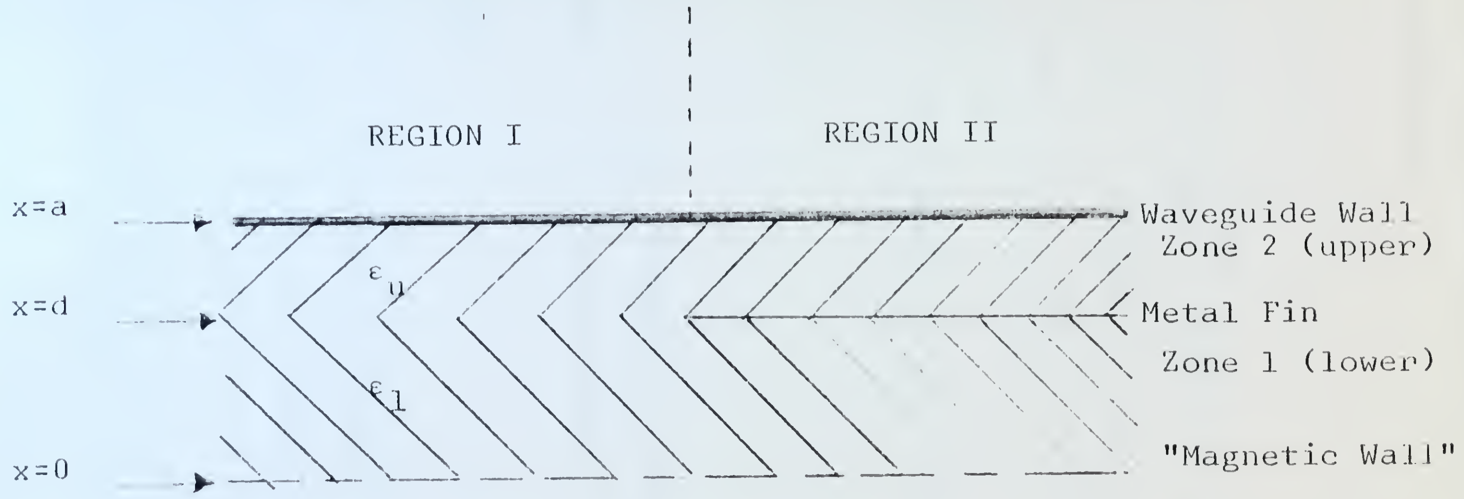


Fig. II-1. E-Plane Bilateral Fin-line Geometry



ε_u = Relative Dielectric Constant, upper

ε_l = Relative Dielectric Constant, lower

Fig. II.2. Simplified Waveguide Geometry

while Zone 2, sometimes called the upper zone, refers to the condition:

$$d \leq x \leq a.$$

Modal eigenvalues in Region I use lower-case subscripts, while those of Region II use upper-case. Regional divisions are occassionally indicated explicitly by the superscripts. "I" and "II".

The Z dependence of all fields is of the form:

$$e^{-\gamma_m z}$$

where γ_m is the propagation constant of the m^{th} mode. Likewise, the time dependence of all fields is of the form:

$$e^{i\omega t}$$

where ω is the radian frequency of the electromagnetic (EM) wave. These terms are understood to multiply all field expressions, and will not be explicitly shown, except where it is more convenient, or constructive to do so.

The general solution to the wave equation has the form:

$$[A_{jk} \cos k_j x_k + B_{jk} \sin k_j x_k]\ e^{i\omega t - \gamma_j t}$$

where the k_j are the associated wave numbers and the x_k are the appropriate directional variables, x or y.

For our purposes, the electric field in the Y direction, E_y, is of greatest interest. In Region I, the appropriate expressions for the normal modes of the E_y field are found to be (Appendix A):

$$\phi_n = \begin{cases} \Lambda_n \cos k_{1n} x & 0 \le x \le d \\ \Omega_n \sin k_{un}(a-x) & d \le x \le a \end{cases} \qquad \text{(II.A.1)}$$

with

$$\Omega_n = \Big[\Big(\frac{\sin^2 k_{nn}(a-d)}{\cos^2 k_{1n} d}\Big)\Big(\frac{d}{2} + \frac{\sin 2k_{1n} d}{4k_{1n}}\Big)$$

$$+ \Big(\frac{a-d}{2} - \frac{\sin 2k_{un}(a-d)}{4k_{un}}\Big)\Big]^{-1/2}$$

$$\Lambda_n = \Omega_n \frac{\sin k_{un}(a-d)}{\cos k_{1n} d} \; .$$

The wave numbers for the n^{th} mode are related by the transcendental equations:

$$\left\{ \begin{array}{ll} k_{1n}^{2} = k_{un}^{2} - k_{o}^{2}(\varepsilon_{u} - \varepsilon_{1}) & \text{(II.A.2)} \\ k_{1n} \tan k_{1n}d = k_{un} \cot k_{un}(a-d) & \text{(II.A.3)} \end{array} \right.$$

where

$$k_{o} = \frac{2\pi}{\lambda_{o}} = \frac{2\pi f}{c} .$$

Equation II.A.2 is the usual dispersion relation, where ε_1 and ε_u are the relative dielectric constants of the two zones. The transcendental equations (II.A.2) and (II.A.3) are solved simultaneously to determine the value of the wave number for each mode in both zones.

The corresponding expressions for Region II are similarly found to be:

$$\psi_{p} = \left\{ \begin{array}{lll} (\frac{2}{d})^{1/2} \cos k_{LP}x & : & 0 \leq x \leq d \\ (\frac{2}{a-d})^{1/2} \sin k_{UP}(z-x) & : & d \leq x \leq a \ . \end{array} \right. \qquad \text{(II.A.4)}$$

The wave number for the p^{th} mode is:

$$k_{LP} = \frac{(2P-1)\pi}{2d} \quad ; \quad 0 \leq x \leq d$$

$$k_{UP} = \frac{P\pi}{(a-d)} \quad ; \quad d \leq x \leq a \ .$$

It should be noted that in Region II, the eigenvalues for k_{LP} are uncoupled from the eigenvalues for k_{UP} so that the mode number, p, runs from 1 to ∞ individually in each zone. The propagation number for the m^{th} mode in Region I is given by:

$$\gamma_m^I = (K_{1m}^{\ 2} - \varepsilon_1 \, k_o^{\ 2})^{1/2} \qquad 0 \leq x \leq a \ .$$

The Region II propagation numbers are given by:

$$\gamma_p^{II} = \begin{cases} (k_{LP}^{\ 2} - \varepsilon_L \, k_o^{\ 2})^{1/2} & 0 \leq x \leq d \\ (k_{UP}^{\ 2} - \varepsilon_U \, k_o^{\ 2})^{1/2} & d \leq x \leq a \ . \end{cases}$$

Positive real values for the propagation number corresponds to evanescent waves. Propagating wave modes occur when the propagation number is imaginary.

B. MODAL ANALYSIS

Any physically realizable electric field may be written as some linear combination of the normal modes. That is:

$$E_y^{I} = \sum_{n=1}^{\infty} A_n \phi_n$$

and

$$E_y^{II} = \sum_{p=1}^{\infty} D_p \psi_p \quad .$$

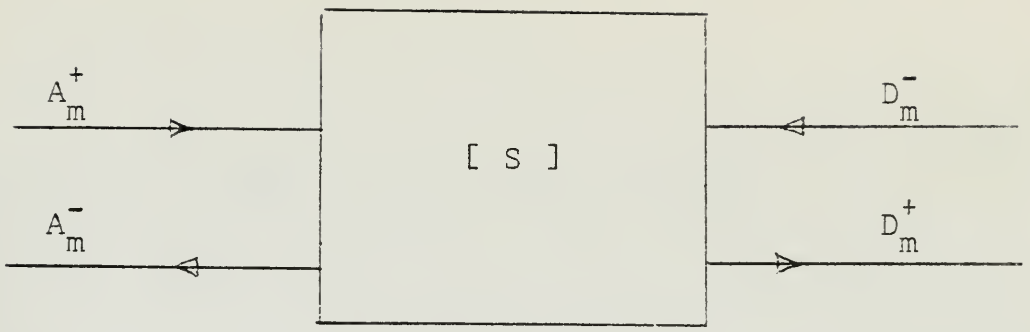
The ϕ_n and ψ_p are the normal modes of the E_y field in Region I and Region II, respectively. The A_n and D_p are the associated amplitudes.

The interface discontinuity may be analyzed as a two port junction, with values as defined in Fig. II-3. The boundary conditions on the ϕ_n and ψ_p [Ref. 4] require that:

$$\sum_{n=1}^{\infty} A_n^{+} \phi_n + \sum_{n=1}^{\infty} A_n^{-} \phi_n = \sum_{p=1}^{\infty} D_p^{+} \psi_p + \sum_{p=1}^{\infty} D_p^{-} \psi_p$$

and

$$\sum_{n=1}^{\infty} Y_n^{I} A_n^{+} \phi_n - \sum_{n=1}^{\infty} Y_n^{I} A_n^{-} \phi_n = \sum_{p=1}^{\infty} Y_p^{II} D_p^{+} \psi_p - \sum_{p=1}^{\infty} Y_p^{II} D_p^{-} \psi_p \quad .$$



A_m^+ = Coefficients of Modes Incident from the Left

A_m^- = Coefficients of Modes leaving junction to the Left

D_m^- = Coefficients of Modes Incident from the Right

D_m^+ = Coefficients of Modes leaving junction to the Right.

[S] = Scattering Matrix

Fig. II-3. Two-port Junction Model of Discontinuity

The characteristic impedance of the n^{th} mode, Y_n, is defined by:

$$-j\omega\mu(H_z)_n = \frac{\partial \phi n}{\partial z} = -\gamma_n \phi_n \rightarrow (H_z)_n = Y_n \phi_n \ .$$

Whence,

$$Y_n = \frac{\gamma n}{j\omega u} \ . \qquad \text{(II.B.1)}$$

The orthogonality of the normal modes implies that:

$$\sum_{n=1}^{\infty} (A_n^+ + A_n^-) \int_o^a \phi_n \psi_m \, dx = \sum_{p=1}^{\infty} (D_p^+ + D_p^-) \int_o^a \psi_p \psi_m \, dx$$

$$= \sum_{p=1}^{\infty} (D_p^+ + D_p^-) \, \delta_{pm}$$

where δ_{pm} is the kronecker delta.

We define the coupling coefficients, H_{mn}, by:

$$H_{mn} \equiv \int_o^a \phi_n \psi_m \, dx \ .$$

Whence,

$$\sum_{n=1}^{\infty} (A_n^+ + A_n^-) H_{mn} = D_m^+ + D_m^- .$$

Similarly, we can write:

$$\sum_{n=1}^{\infty} Y_n^I (A_n^+ - A_n^-) \int_0^a \phi_n \phi_m \, dx = Y_m^I (A_m^+ - A_m^-)$$

$$= \sum_{p=1}^{\infty} Y_p^{II} (D_p^+ - D_p^-) \int_0^a \psi_p \phi_m \, dx$$

or, since the p is a dummy summation index,

$$Y_m^I (A_m^+ - A_m^-) = \sum_{n=1}^{\infty} Y_n^{II} (D_n^+ - D_n^-) H_{nm} .$$

By representing the A and D amplitudes as vectors, and the H coupling coefficients and Y impedance terms as matrices, these relationships may be expressed more succinctly as:

$$[H_{mn}][A_n^+ + A_n^-] = [D_m^+ + D_m^-]$$

$$[Y_m^I]\,[A_m^+ - A_m^-] = [Y_n^{II}][H_{mn}]^T\,[D_m^+ - D_m^-] .$$

The $[H_{mn}]^T$ represents the transpose of the matrix $[H_{mn}]$. The elements of $[H_{mn}]$ may be evaluated by direct substitution of the expressions for the normal modes (Eqs. II.A.1 and II.A.4) into the definition (II.B.2). From Appendix B we write:

$$H_{mn} = \Lambda_n \left(\frac{2}{d}\right)^{1/2} ((-1)^m \cos k_{ln} d)\left(\frac{k_{Lm}}{k_{ln}^2 - k_{Lm}^2}\right)$$

$$+ \Omega_n \left(\frac{2}{a-d}\right)^{1/2} ((-1)^m \sin k_{un}(a-d))\left(\frac{k_{Um}}{k_{un}^2 - k_{Um}^2}\right) .$$

The scattering matrix for a single junction is defined in Appendix C to have matrix elements (which are themselves matrices) as follows:

$$[S_A] = \begin{bmatrix} S_{A11} & S_{A12} \\ S_{A21} & S_{A22} \end{bmatrix}$$

$$S_{A11} = [Y^I + H^T Y^{II} H]^{-1}[Y^I - H^T Y^{II} H]$$

$$S_{A12} = 2[Y^I + H^T Y^{II} H]^{-1}[H^T Y^{II}] = [I - S_{A11}]H^T \qquad \text{(II.B.3)}$$

$$S_{A21} = 2[I + H(Y^I)^{-1} H^T Y^{II}]^{-1} H = H[I + S_{A11}]$$

$$S_{A22} = [I + H(Y^I)^{-1} H^T Y^{II}]^{-1}[H(Y^I)^{-1} H^T Y^{II} - I] = -H[S_{A11}]H^T .$$

Note that each of the individual elements, H, Y, T, and I are themselves matrices. For a single fin-line strip there is a scattering matrix associated with the left boundary (minimum Z), $[S_A]$, described above, a transmission matrix associated with the width of the strip, $[T_D]$, and a scattering matrix associated with the right boundard, $[S_B]$. The expression for an equivalent scattering matrix for the net effect of $[S_A]$, $[T_D]$, and $[S_B]$, is developed in detail in Appendix D. The result is:

$$[S_E] = \begin{bmatrix} S_{E11} & S_{E12} \\ S_{E21} & S_{E22} \end{bmatrix}$$

where:

$$\begin{aligned}
S_{E11} &= [S'_{A11}]+[S'_{A12}][I-S_{B11}\ S'_{A22}]^{-1}\ [S_{B11}\ S'_{A21}] \\
S_{E12} &= [S'_{A12}][I - S_{B11}\ S'_{A22}]^{-1}[S_{B12}] \\
S_{E21} &= [S'_{A21}][I - S_{B22}\ S'_{A11}]^{-1}[S_{B21}] \\
S_{E22} &= [S'_{A21}][I - S_{B22}\ S'_{A11}]^{-1}[S_{B22}\ S'_{A12}] + [S'_{A22}]
\end{aligned} \qquad \text{(II.B.4)}$$

and

$$S'_A = [T_D][S_A][T_D] \ .$$

The equivalent scattering matrix for a fin-line with and arbitrary number of fins may be determined by repeated application of equations (II.B.4), with the appropriate transmission matrices used in the cascade.

III. COMPUTER AIDED DESIGN PROGRAM

The CAD (computer aided design) program has two functions: 1) design of a filter (description of physical dimensions) based upon user specified characteristics; and 2) analysis of a physically described fin-line filter. The user has the option of directly entering the analysis portion of the CAD if filter dimensions have been determined by some other means. In most cases, however, the user will specify the desired response of the fin-line filter (bandedge frequencies, passband ripple and upper skirt rejection) and the CAD will determine the filter dimensions. These dimensions are then automatically passed to the analysis portion of the CAD.

The design portion of the CAD is built upon the theoretical work of Levy [Refs. 6, 7] and contains a modified form of a subroutine developed by Shih in [Ref. 2]. The design technique is fundamentally a conventional network synthesis. The insertion-loss characteristic of the distributed filter is approximated by the equation:

$$L = 1 + h^2 T_n^2 \left[\frac{\lambda_g}{\lambda_{go}} \frac{\sin(\lambda_g/\lambda_{gc})}{\sin \theta_o'}\right] .$$

where:

h is the passband ripple

λ_g is the guide wavelength

λ_{go} is the guide wavelength at the filter center frequency

$$\sin\theta_o' = \frac{\lambda_{g1}}{\lambda_{go}} \sin \frac{\lambda_{go}}{\lambda_{g1}} = \frac{\lambda_{g2}}{\lambda_{go}} \sin \frac{\lambda_{go}}{\lambda_{g2}}$$

$\lambda_{g1}(\lambda_{g2})$ is the guide wavelength at filter bandedge, $f_1(f_2)$

T_n is the first-kind Chebyshev polynomial of degree n

n is the number of filter resonators.

The insertion loss equation is evaluated for the input specifications to determine the number of resonators required. To properly determine the number of resonators for the general case, it was necessary to develop subroutines to solve simultaneously the transcendental equations for the wave numbers of the eigenmodes. The functional dependency of the insertion loss equation, above, on guide wavelength is ambiguous for the Class II and Class III filter. Thus, it was also necessary to determine an "effective" guide wavelength which accounts for the fact that the wavelength changes as the wave propagates from one dielectric region into another. It is this effective guide wavelength which is used in Levy's formula. The required reflection coefficients of the n+1 fins are then derived from the Chebyschev polynomial. Next, the scattering matrix for a finite septum (Eqs. II.B.3) is evaluated by a bisection technique to determine the n+1 fin dimensions which satisfy

these reflection coefficient requirements. Finally, the resonator dimensions are determined so that the electrical length of each resonator is (1/2) λ_{go}.

With the dimensions of the filter thus determined, the CAD then performs a complete frequency response analysis based upon the mode-matching technique described in Sections II.A and II.B. It should be noted that the equal-ripple Chebyshev polynomial expression very accurately matches the computed response when the filter is narrow band (less then 4% bandwidth). The agreement between the Chebyshev filter approximation and the mode-matching scattering analysis deteriorates as the filter bandwidth increases. A thorough discussion of this phenomenon is given by Shih in [Ref. 8] along with new formulae which account for the frequency dependencies of the step-impedances. However, excellent agreement between design criteria and predicted response has been obtained by employing an empirically derived offset to the lower bandedge frequency. That is, if the user specifies the filter bandedges to be F1 and F2, the design portion is actually computed for bandedge frequencies:

$$F1' = F1\left(1 - \left(\frac{2(F2-F1)}{F2+F1}\right)^2\right), \text{ and } F2.$$

The program listing given in Appendix F includes those subroutines which were developed as a consequence of the previously discussed theory. Subroutine TREQ develops eigenmode wave numbers for all three filter classes. Subroutine PROPAG determines the corresponding propagation numbers. Subroutine SMATRI determines the values of the H matrix coupling coefficients, and the elements of the scattering matrix. Subroutines CASCAD, DSUM, and TRANSM are used to determine the net effect of several cascaded fins and resonators, as discussed in Appendix E.

Certain subroutines used in the design portion of the program are substantially the work of Shih [Ref. 2], and are not included in the program listing. Also omitted are certain mathematical and algebraic routines required for the matrix manipulations.

IV. PROGRAM VALIDATION

A. OVERVIEW

The first phase of program validation was conducted as critical subroutines became available. For example, the subroutine which determines wave mode numbers was tested for special circumstances for which the values could be verified by means of a hand calculator. A series of tests were then made to assure convergence to this limiting case. Professor Y. C. Shih kindly modified subroutines extracted from his work [Ref. 2] to output values at intermediate stages of his analysis routine. These numerical values were of interest because they were determined from closed-form expressions for the reflection coefficients, and employed a residue calculus technique. Thus, the corresponding values determined by the new program were evaluated from a completely different set of expressions and based upon a fundamentally different approach to the problem. Correspondence between equivalent values was considered good to within the accuracy of the numerical process.

Predicted filter responses were compared to actual filter performance to validate further the computer aided design and analysis program. Dimensions for Class I and Class II filters described by Shih [Ref. 2] and Arndt, et al, [Ref. 3] were inserted into the analysis portion of

the CAD and filter performance was predicted over an appropriate frequency range. The agreement between predicted response and published filter performance was excellent. Lastly, final validation of the CAD was accomplished by means of locally designing, constructing and testing three Class I and two Class II fin-line filters.

B. FILTER CONSTRUCTION AND TEST

The locally constructed test filters were designed to be resonant within the 8 to 12 GHz band. This frequency band choice was selected to simplify both filter construction and test.

The three Class I filters were manually cut with scissors and razor blades from a 2 mil(0.002 inch) copper foil. The narrow band Class III filter was made by manually cutting away the 2 mil copper layer from 1/8" copper clad substrate (Rexolite 1422). The substrate for the wideband Class III filter was a slab of styrofoam cut from a packing form. Conducting fins were cut from 2 mil copper tape and pressed onto the styrofoam slabe to form the filter structure.

The test fixture used was a specially machined ten inch aluminum section of WR-90 compatible waveguide (0.9 by 0.4 inch, internal), modeled after a design by Knorr [Ref. 9]. This guide consisted to two longitudinal sections which were bolted together. The transverse dimension of the

Class I filter was made equal to the test fixture exterior dimension. It was a simple matter, therefore, to separate slightly the test guide halves, slip in the fin-line structure, and tighten the clamping bolts. While this introduced a 2 mil dimension distortion in the center area of the test fixture, no adverse effects were noted.

The fin-line structure of the Class III filter was pressed into the opened waveguide groove. A small spot of rubber cement served to hold the dielectric substrate against the guide wall.

Filter electrical performance was measured with the aid of an HP-8409 automated network analysis system.

C. RESULTS

A plot of normalized throughput power versus frequency for seven filters is shown in Figures IV-1 through IV-7, for Filters #1 through #7, respectively. Filters #1 through #4 and #7 were fabricated by the authors. For these figures the continuous curve is a plot of the predicted filter response generated by the CAD. The circles contain measurement data points. Filters #5 and #6 are representative filters described by Arndt, et al [Ref. 3]. Again, the line is the CAD generated plot, but the data points on these curves were taken from figures contained in [Ref. 3]. Table IV-1 contains the physical descriptors of the filters.

Filters #1 and #2 are Class III type structures; filters #3, #4 and #7 are Class I; filters #5 and #6 are Class II. In general, the shape of the filter response corresponds well to the simulated filter. Actual filter passband ripple was more than predicted, and varied from a best case of 0.1 dB (#1) to a worst case of 3.0 dB (#2). Best case insertion loss (Filters #1 and #7) was about 0.3 dB. Modifications to existing filters and multiple construction attempts at the same design suggests that the majority of the discrepancy in predicted and actual response was due to error in the hand-out filter dimensions.

The good agreement between predicted and actual filter response is readily seen for filters #4, #6 and #7 (Figures IV-4, IV-6, IV-7). In other instances the agreement is less apparent because of the expanded scale of the plot. For example, the discrepancy between predicted and actual response of filter #1 may be almost entirely accounted for by a shift in center frequency of about 150 MHz. This 150 MHz shift represents about a 1.7% error in center frequency and could result from a construction error in resonator dimension of about 0.3 mm.

Filter #7 is particularly interesting because it demonstrates the utility of the program. This filter was designed to satisfy a requirement of a physics researcher. Total time logged on the computer was about 15 minutes.

A copy of the output to the CRT is given in Appendix G. The CAD determined filter dimensions were scribed onto a sheet of copper foil and the filter was cut out by hand. Total construction time was about one hour. Figure IV-8 is a copy of the test equipment output, with notations added. The minimum measured insertion loss was 0.28 dB at 8.604 GHz. Passband ripple was measured at 0.39 dB. The lower 3 dB point was measured at 8.360 GHz and the higher 3 dB point was measured at 8.823 GHz. Thus, the CAD analysis values for the 3 dB frequency cutoffs of about 8.37 GHz and 8.85 GHz compare to within 0.3% of the measured values. The researcher considered the more than 60 dB of out-of-band rejection provided by this filter to be quite adequate.

D. DISCUSSION

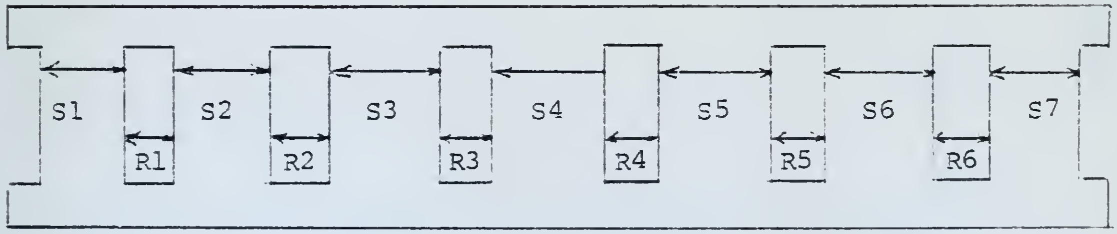
Experiences related to the design, fabrication and test of the fin-line filters motivates us to catalogue a number of observations which may be useful to others.

First, it should be stressed that the filters constructed were very crude by industry standards. Dimensional tolerances are estimated at ± 0.4 mm. Thus, the dimensional accuracy of the smallest fins is roughly bounded by ± 40%. The reasonably good electrical performance of these filters was, therefore, all the more striking. Also, it should be noted that the approximate 150 MHz shift in center frequency for filter #1 (narrow band Class III) can be the result of about a 0.3 mm error in the construction of the resonator dimension.

TABLE IV-1

DESIGN DATA FOR CAD VALIDATION TEST FILTERS

Filter #	1	2	3	4	5	6	7
a(cm)	1.143	1.143	1.143	1.143	.7895	.188	1.143
d(cm)	0.508	0.508	0.508	0.508	.0127	.00635	0.508
ε_u (upper)	2.550	1.030	1.000	1.000	1.0	1.0	1.000
ε_l (lower)	1.000	1.000	1.000	1.000	2.22	2.22	1.000
F1(GHz)	8.625	9.950	8.450	11.30	15.00	66.0	8.400
F2(GHz)	8.775	10.95	8.850	11.75	15.60	67.0	8.800
# Strips	3	6	4	4	4	4	7
# Res	2	5	3	3	3	3	6
S1 (cm)	.0959	0.1485	.0732	.4995	.2075	.0347	.0906
S2 (cm)	.4928	0.7782	.4185	1.4252	.7760	.2038	.4794
S3 (cm)	.0959	1.0040	.4185	1.4252	.7760	.2038	.5961
S4 (cm)	---	1.0040	.0732	.4995	.2075	.0347	.6134
S5 (cm)	---	0.7782	---	---	---	---	.5961
S6 (cm)	---	0.1485	---	---	---	---	.4794
S7 (cm)	---	---	---	---	---	---	.0906
R1 (cm)	1.5044	1.1435	1.9991	.9398	.8400	.1895	2.0480
R2 (cm)	1.5044	1.1142	2.0728	.9265	.8400	.1900	2.1227
R3 (cm)	---	1.1104	1.9991	.9398	.8400	.1895	2.1280
R4 (cm)	---	1.1142	---	---	---	---	2.1280
R5 (cm)	---	1.1435	---	---	---	---	2.1227
R6 (cm)	---	---	---	---	---	---	2.0480



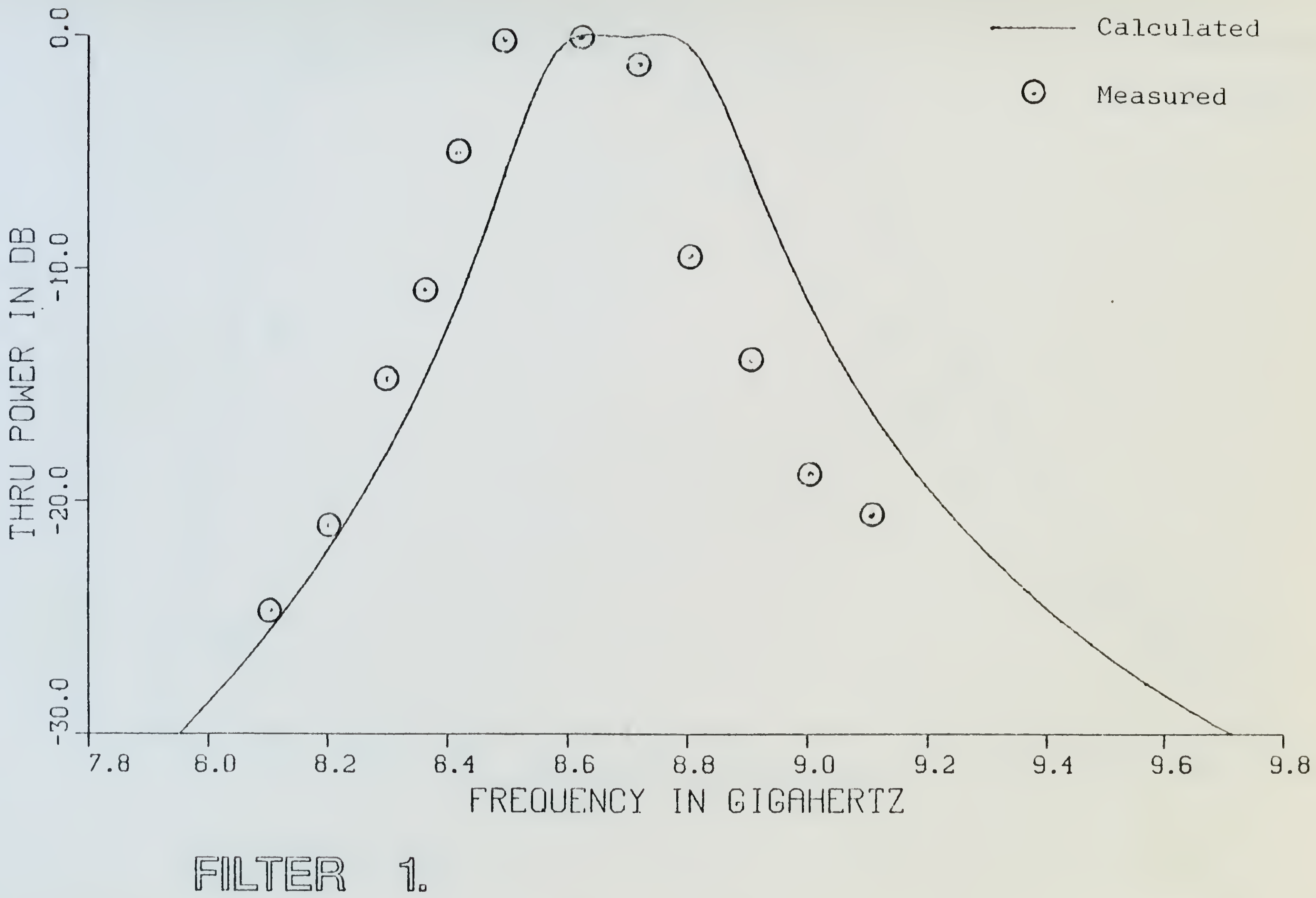


Fig. IV-1. Calculated and Measured Insertion Loss of Fin-line #1

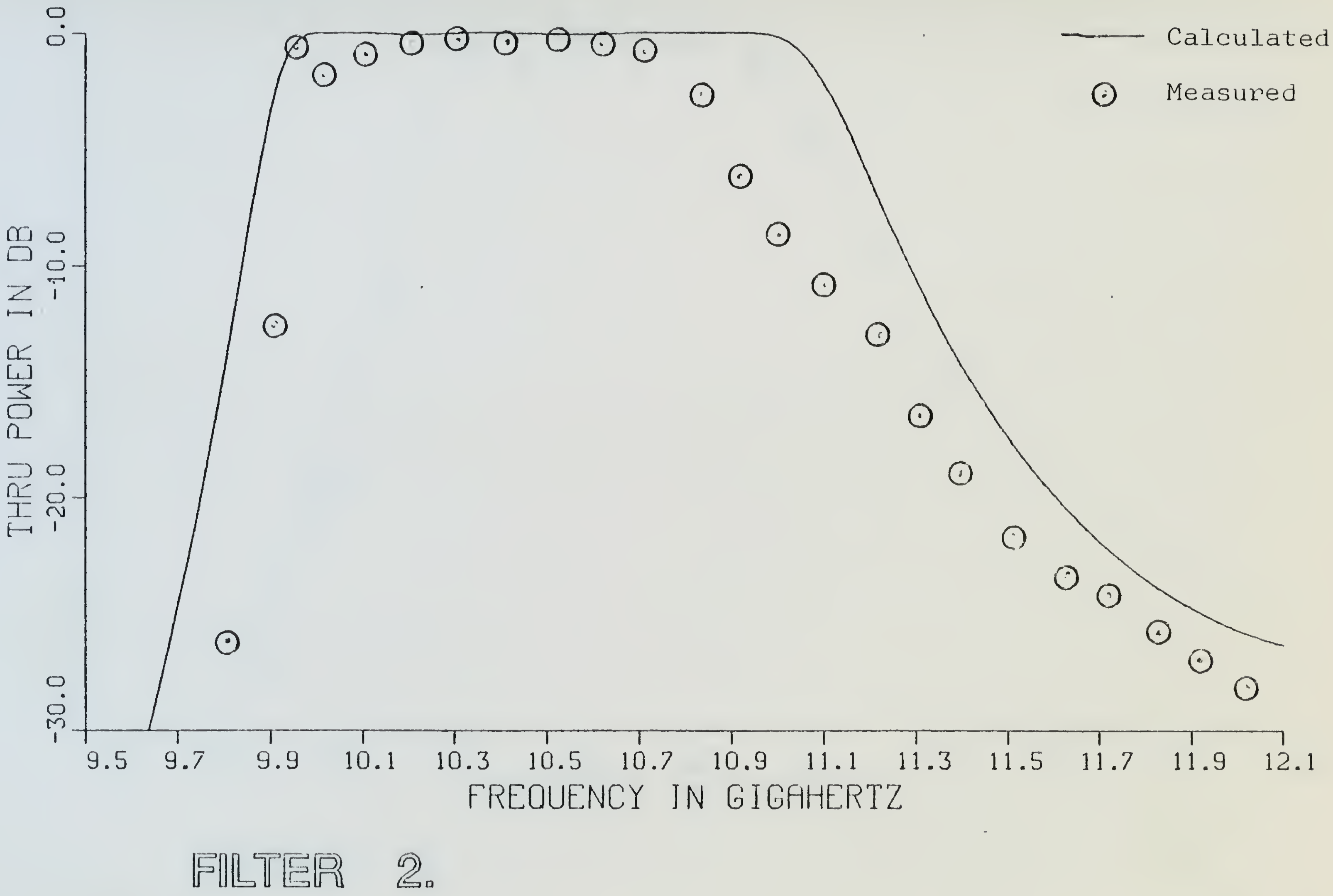


Fig. IV-2. Calculated and Measured Insertion Loss of Fin-line #2

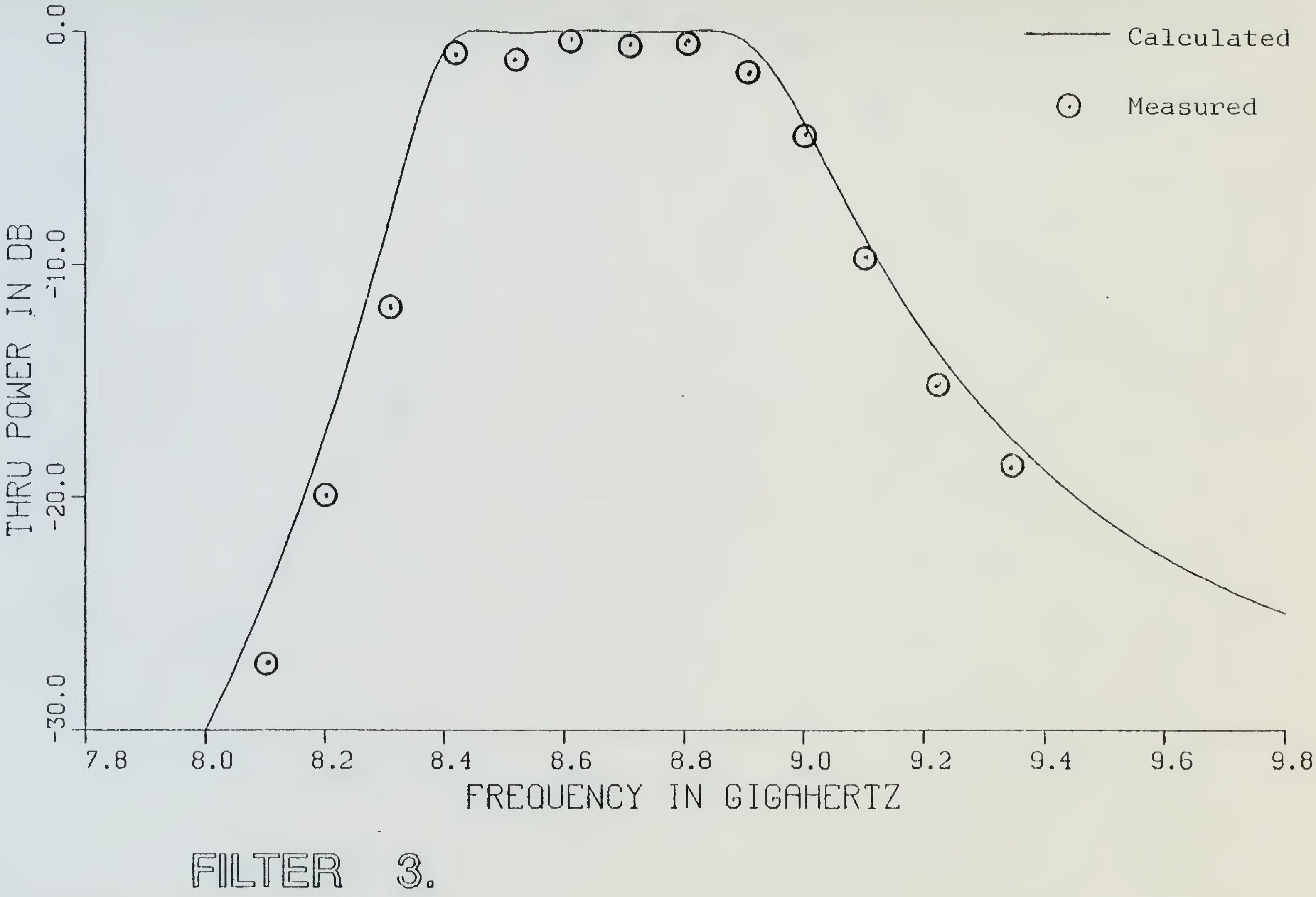


Fig. IV-3. Calculated and Measured Insertion Loss of Fin-line #3

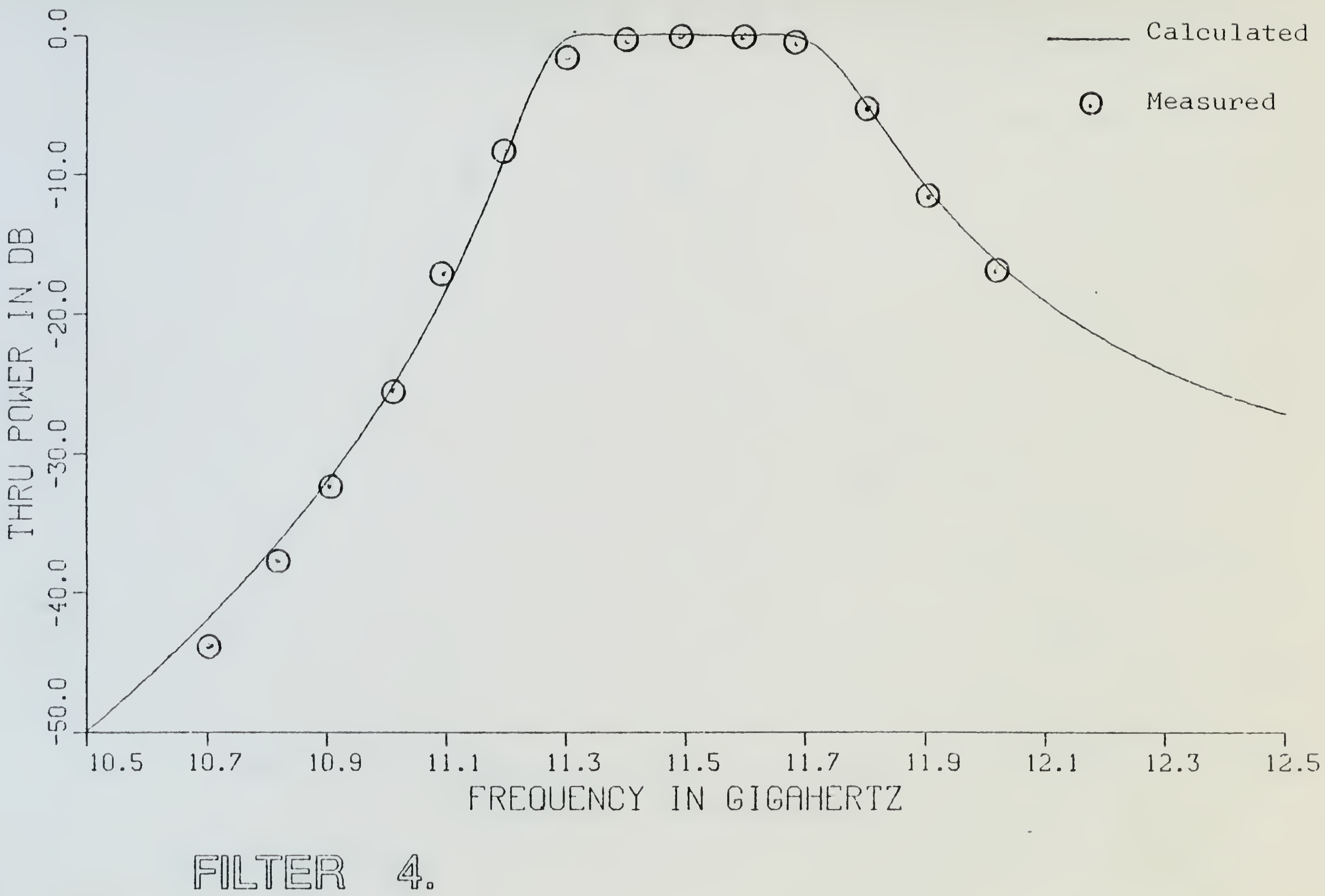


Fig. IV-4. Calculated and Measured Insertion Loss of Fin-line #4

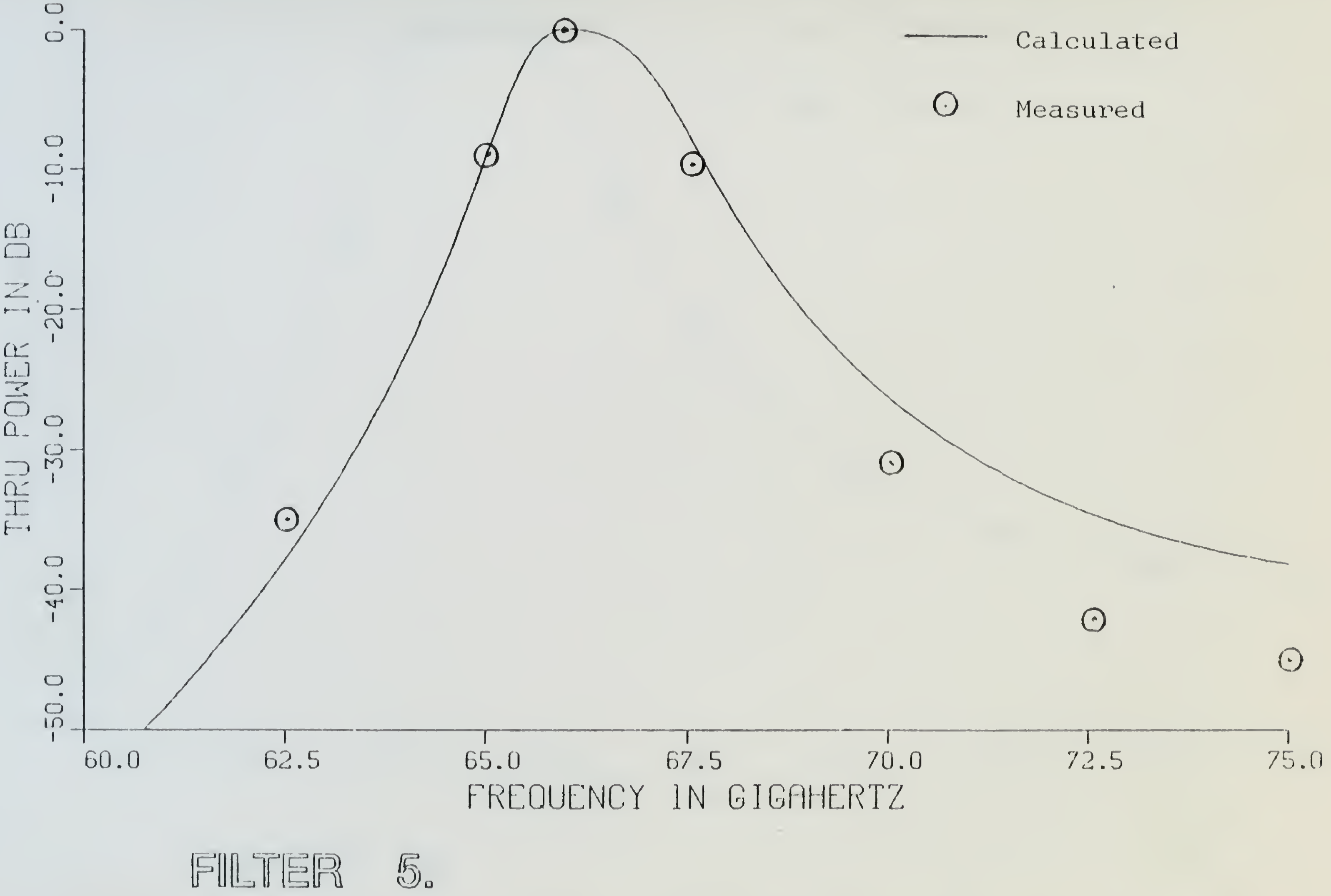


Fig. IV-5. Calculated and Measured Insertion Loss of Fin-line #5

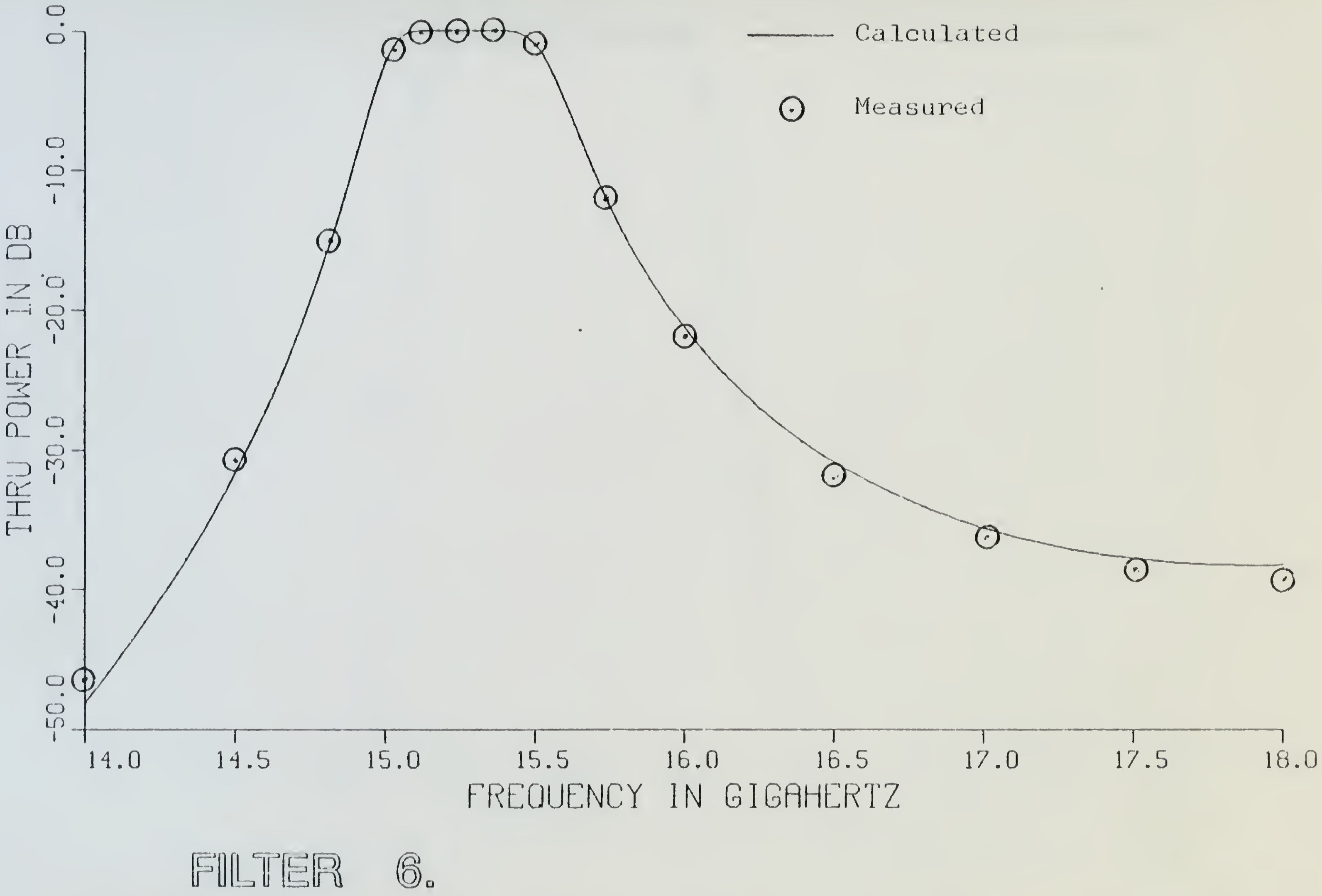


Fig. IV-6. Calculated and Measured Insertion Loss of Fin-line #6

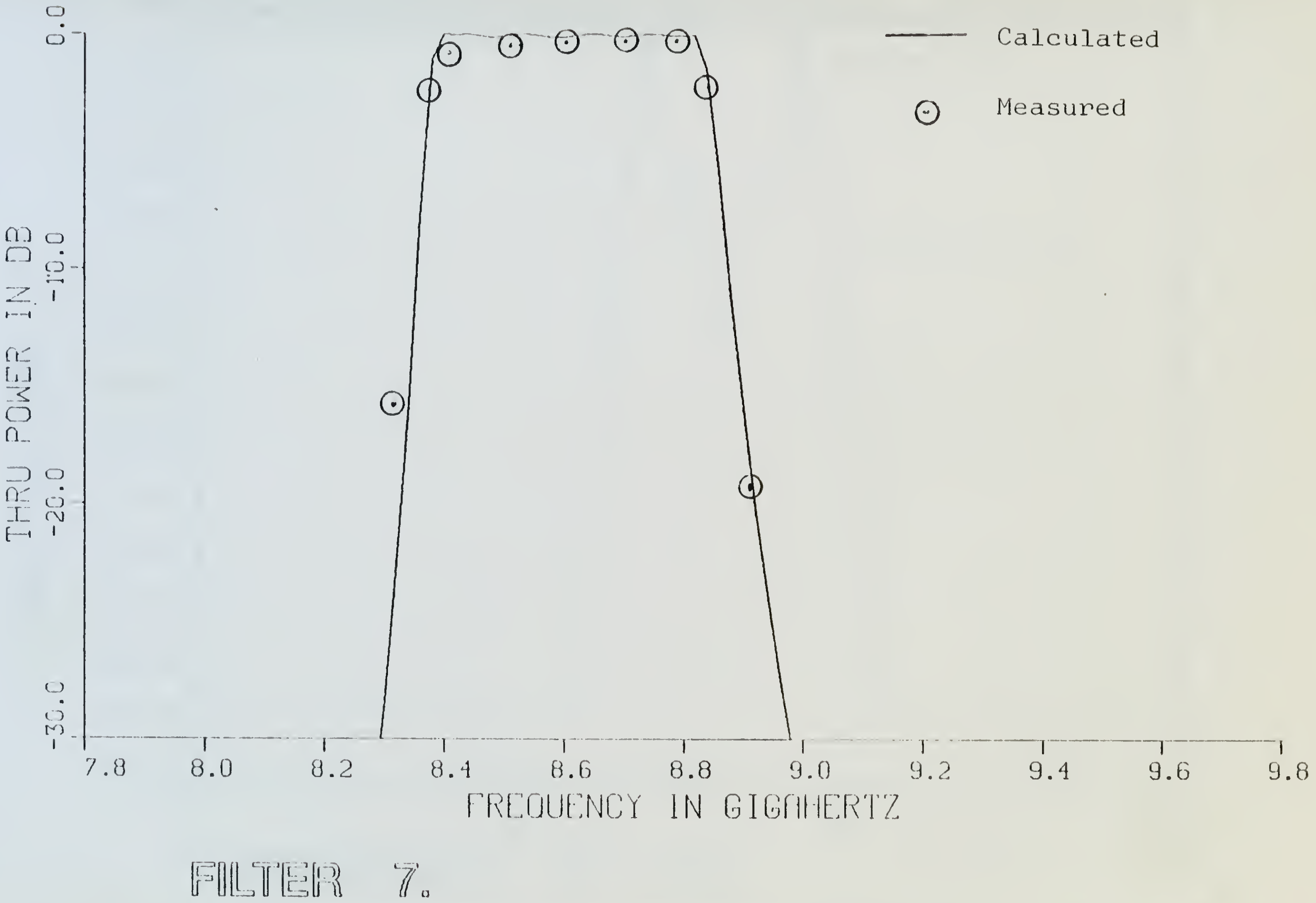


Fig. IV-6. Calculated and Measured Insertion Loss of Fin-line #7

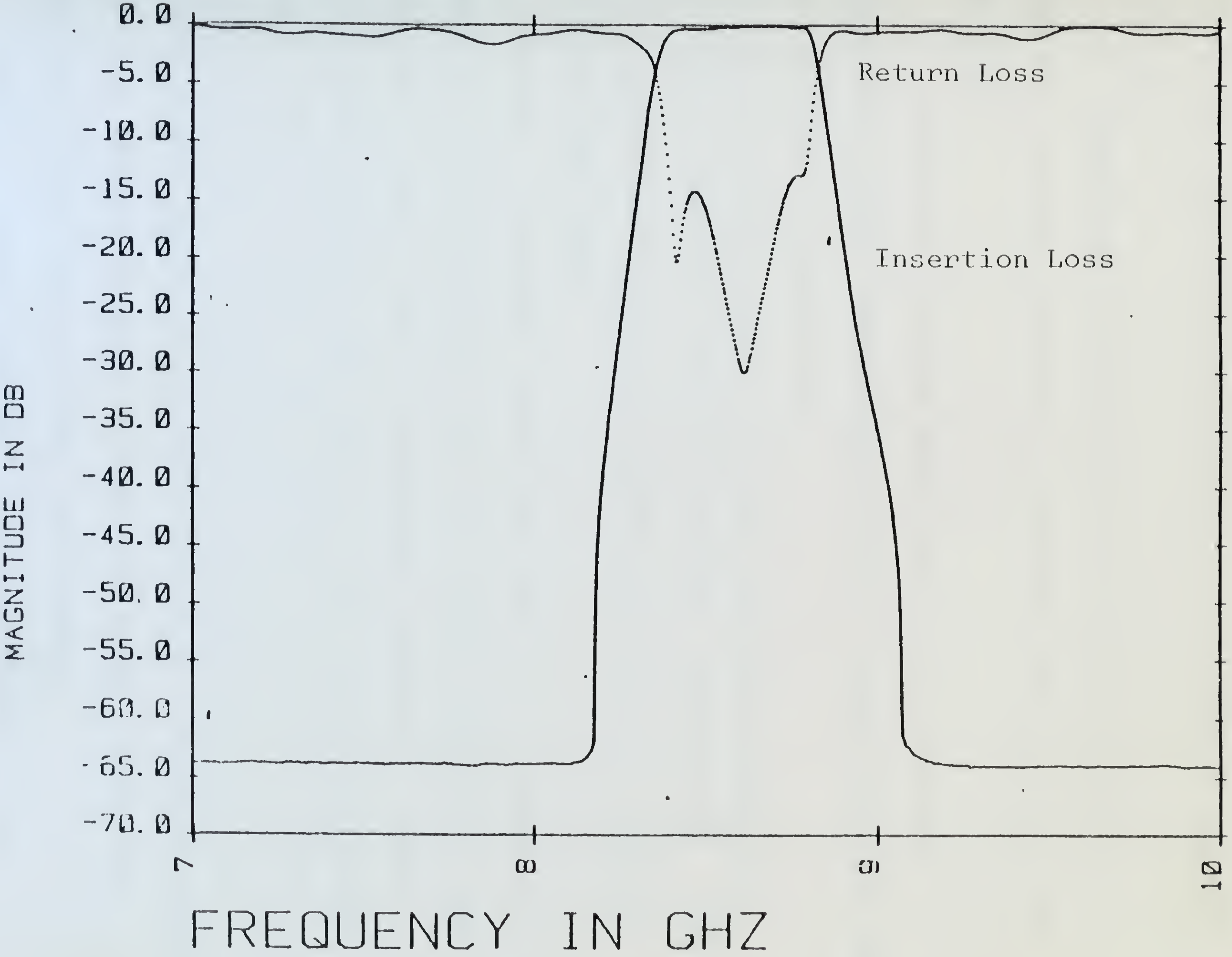


Fig. IV-8. Filter #7 Experimental Curve

Secondly, difficulties associated with the fabrication of the Class III filters suggests the need for an improved construction technique. Any new such technique needs to address the two major shortcomings of the method employed. These are:

1) Difficulty in longitudinally aligning the two separate fin-line sections to maintain symmetry about the x=0 axis.

2) Persistent problems associated with inadequate electrical contact between the filter's conducting fins and the waveguide's broad walls.

Failure to correct either of these recurring tendencies resulted in severely reduced electrical performance. Thus, the original motivation for developing Class III filters may have been false.

Thirdly, dielectric substrates should be tapered. For example, the narrow band Class III filter (filter #1) was originally constructed on rectangular dielectric slabs. The entire insertion loss curve of this filter exhibited about 12 dB of ripple. The insertion loss data points plotted are for the same filter, but with the addition of dielectric ramps on all four slab ends. Passband ripple was thus reduced to about 0.1 dB, and ripple along the rejection skirts was no longer noticeable.

Finally, from an applications view point, it is important to realize that the strip widths exhibit a

correlation to passband ripple. That is, as the ripple is decreased, the fin-line strip dimension decreases. Strip width may be increased by either specifying a larger ripple, or by forcing additional resonators by requiring sharper rejection skirts. Wider strip widths are preferrable simply because of achieveable mechanical tolerances, and structural integrity.

V. CONCLUSIONS AND RECOMMENDATIONS

The numerical analysis technique employed by the authors will always produce a result. The question is whether this result has any correlation to the physical world. It was found that this numerical analysis yields values essentially identical to those obtained by Shih [Ref. 2], who employed a completely different approach, and evaluated entirely different expressions. This suggests that both approaches are valid. Furthermore, the good agreement between all predicted filter responses and filter performance strongly suggests that the procedure applied was theoretically sound, and properly executed.

The CAD program produced by this study is not an end in itself, but a design tool. It should be used to answer a number of design questions. It is recommended that an organized study be conducted to determine the following:

1) Under what conditions is the center-line structure preferrable to a bilateral structure?

2) For the bilateral fin-line, what determines the optimal transverse fin-line location?

3) Are there optimal values for the relative permittivities in the Class II and Class III filter designs?

4) How sensitive is filter reponse to dimensional tolerances?

5) Does the current filter design meet engineering requirements, or is the use of a design/response optimization routine justified?

6) To what extent can the number of modes retained in the numerical analysis be reduced without adversely reducing accuracy?

Finally, to determine more accurately the degree of correspondence between simulated and physical filter performance it will be necessary to construct higher quality devices. In particular, the fin-line structure should be produced by photo-etching techniques to minimize dimensional errors.

APPENDIX A

REGION I EIGENMODES

The solution to the general wave equation for an EM wave in a guide with disimilar dielectric zones, as shown in Fig. II-1 (Region I), is found in a manner similar to that for a simple waveguide. However, in this instance, the eigenvalues for the propagation numbers are not explicitly expressible. Instead, a pair of transcendental equations is found (A.1 and A.2) which must be solved simultaneously to determine each eigenvalue.

For incident TE_{mo} (m odd) modes, the Z component of the magnetic field (H_z) in the wave guide will have a value of zero along the x=0 plane. It is convenient, therefore, to impose the condition of a "magnetic wall" along x=0, on which a boundary condition is that

$$H_z \Big|_{x=0} = 0.$$

By referring to the geometry of the waveguide depicted in Fig. II-2, we can write the form of the E_y fields as:

$$\phi_{lm} = A_m \sin k_{lm}x + B_m \cos k_{lm}x$$

$$\phi_{um} = C_m \sin k_{um}x + D_m \cos k_{um}x \ .$$

At the magnetic wall, x=0, the boundary condition imposed is:

$$\left[-jw\mu\ H_z = \frac{\partial Ey}{\partial x} - \frac{\partial Ex}{\partial y}\right]_{x=0} = 0 \ .$$

But since $(\frac{\partial}{\partial y}) = 0$ for all fields, we can write:

$$\left[\frac{\partial Ey}{\partial x}\right]_{x=0} = 0 = \left[K_{1m}A_m \cos k_{1m} - k_{1m}B_m \sin k_{1m}x\right]_{x=0} \ .$$

Whence, $A_m=0$.

The second boundary condition to be satisfied is that:

$$[E_y]_{x=a} = 0 \ .$$

So that:

$$C_m \sin k_{um}a + D_m \cos k_{um}a = 0 \ .$$

Whence,

$$D_m = -C_m \tan k_{um}a.$$

Therefore, the E_y fields in Region I is given by:

$$\phi_{1m} = B_m \cos k_{1m}x; \qquad 0 \leq x \leq d$$

$$\phi_{um} = C_m [\sin k_{um}x - \tan k_{um}a \cos k_{um}x]; \qquad d \leq x \leq a .$$

Or, employing a trigonometric identity, E_{yu} may be expressed as:

$$\phi_{um} = C_m \frac{\sin k_{um} (a-x)}{\cos k_{um} a} = \Omega_m \sin k_{um}(a-x) .$$

Finally, $E_{y1} = E_{yu}$ at the boundary of the two zones. That is:

$$B_m \cos k_{1m}d = \Omega_m \sin k_{um}(a-d).$$

From which:

$$B_m = \Omega_m \frac{\sin k_{um}(a-d)}{\cos k_{1m}d} .$$

Likewise, the Z component of the magnetic field must be continuous across the boundary. So that:

$$[H_{z1} = H_{zu}]_{x=d} .$$

Whence:

$$B_m k_{1m} \sin k_{1m} d = \Omega_m \cos k_{um}(a-d).$$

Substituting for B_m above, we find that:

$$k_{1m} \tan k_{1m} d = k_{um} \cot k_{um}(a-d). \tag{A.1}$$

The second equation which the propagation numbers must satisfy is the usual dispersion relation for an EM wave propagation through a dielectric discontinuity [Ref. 4].

$$k_{1m}{}^2 = k_{um}{}^2 - k_o{}^2 (\varepsilon_u - \varepsilon_1). \tag{A.2}$$

The amplitudes of the eigenmodes may be determined by applying the orthogonality property of the modes. That is, trigonometric identities may be used to rewrite the expressions for the eigenmodes as follows:

$$\phi_{1m} = B_m \cos k_{1m} x = \Lambda_m \cos k_{1m} x; \quad 0 \leq x \leq d$$

$$\phi_{um} = \Omega_m \sin k_{um}(a-x).$$

The orthogonality of these modes is exploited by integrating the product of mode pairs across the width of the guide.

$$\int_0^a \phi_m \; \phi_n dx = \delta_{mn}$$

so that,

$$\int_0^d \Omega_n \cos^2 k_{1m} x + \int_0^a \Omega_n \sin^2 k_{um}(a-x)dx = 1 .$$

Whence,

$$\Omega_m = [(\frac{\sin^2 k_{um}(a-d)}{\cos^2 k_{1m} d})(\frac{d}{2} + \frac{\sin^2 k_{1m} d}{4 k_{1m}})$$

$$+ (\frac{(a-d)}{2} - \frac{\sin^2 k_{um}(a-d)}{4 k_{um}})]^{-1/2}$$

$$\Lambda_m = \Omega_m \frac{\sin k_{um}(a-d)}{\cos k_{1m} d} .$$

APPENDIX B

DERIVATION OF EXPRESSIONS FOR H-MATRIX ELEMENTS

The elements of the H-Matrix are defined by:

$$H_{mn} = \int_o^a \phi_n \psi_m \, dx$$

where

$$\phi_n = \begin{cases} \Lambda_n \cos k_{1n} x & : \; 0 \le x \le d \\ \Omega_n \sin k_{un}(a-x) & : \; d \le x \le a \end{cases} \qquad \text{(II.A.1)}$$

$$\psi_m = \begin{cases} \left(\frac{2}{d}\right)^{1/2} \cos k_{1m} x & : \; 0 \le x \le d \\ \left(\frac{2}{a-d}\right)^{1/2} \sin k_{um}(a-x) & : \; d \le x \le a\,. \end{cases} \qquad \text{(II.A.4)}$$

We have therefore:

$$H_{mn} = \int_o^d (\Lambda_n \cos k_{1n} x)\left(\frac{2}{d}\right)^{1/2} (\cos k_{1m} x)dx$$

$$+ \int_d^a (\Omega_n \sin k_{un}(a-x))\left(\frac{2}{a-d}\right)^{1/2} (\sin k_{um}(a-x))dx$$

$$H_{mn} = \Lambda(\frac{2}{d})^{1/2} \quad [\frac{\sin(k_{ln}-k_{Lm})d}{2(k_{ln}-k_{Lm})} + \frac{\sin(k_{ln}+k_{Lm})d}{2(k_{ln}+k_{Lm})}$$

$$- \Omega_m(\frac{2}{a-d})[\frac{\sin(k_{un}+k_{Um})(a-d)}{2(k_{um} + k_{Um})} - \frac{\sin(k_{un}-k_{Um})(a-d)}{2(k_{un}-k_{Um})}].$$

$$H_{mn} = \Lambda_n(\frac{2}{d})^{1/2} \quad [(-1)^m \cos k_{ln}d][\frac{k_{lm}}{k_{ln}^{\;2} - k_{Lm}^{\;2}}]$$

(II.B.2)

$$+ \Omega_m(\frac{2}{a-d})^{1/2} \quad [(-1)^m \sin k_{un}(a-d)][\frac{k_{Um}}{k_{un}^{\;2} - k_{Um}^{\;2}}] \quad .$$

APPENDIX C

JUNCTION SCATTERING MATRIX

Consider the waveguide discontinuity as a two-port junction problem, as represented schematically in Fig. II-3, where (a_n^+, a_n^-) and (b_n^-, b_n^+) are the amplitudes of the incident and scattered modal fields in Region I and II, respectively.

The electric field is a single-valued function of Z. Hence, at the junction boundary, Z=0, we can write:

$$\sum_{n=1}^{\infty} a_n^+ \phi_n + \sum_{n=1}^{\infty} a_n^- \phi_n = \sum_{n=1}^{\infty} b_n^+ \psi_n + \sum_{n=1}^{\infty} b_n^- \psi_n . \tag{C.1}$$

Similarly, the relationship for the x-component of the magnetic field, H_x, is:

$$\sum_{n=1}^{\infty} Y_n^I a_n^+ \phi_n - \sum_{n=1}^{\infty} Y_n^I a_n^- \phi_n$$

$$= \sum_{n=1}^{\infty} Y_n^{II} b_n^+ \psi_n - \sum_{n=1}^{\infty} Y_n^{II} b_n^- \psi_n . \tag{C.2}$$

To utilize the orthonormality of the eigenmodes, we multiply C.1 by ψ_m and integrate across the waveguide.

$$\sum_{n=1}^{\infty} (a_n^+ + a_n^-) \int_0^a \phi_n \psi_m dx = \sum_{n=1}^{\infty} (b_n^+ + b_n^-) \int_0^a \psi_n \psi_m dx$$

$$\sum_{n=1}^{\infty} (a_n^+ + a_n^-) H_{mn} = b_m^+ + b_m^- \quad . \tag{C.3}$$

We define the values H_{mn} as:

$$H_{mn} = \int_0^a \phi_n \psi_m dx.$$

Likewise, multiplying equation C.2 by ϕ_m and integrating yields:

$$Y_m^I (a_m^+ - a_m^-) = \sum_{n=1}^{\infty} (b_n^+ - b_n^-) Y_n^{II} H_{nm} . \tag{C.4}$$

The wave impedances of the normal modes, Y_n, may be represented as diagonal matrices, the values H_{mn} as an m by n matrix, and the amplitudes of the normal modes as vectors. Equations C.3 and C.4 may then be expressed as follows (subscripts have been omitted for simplicity).

$$[H]\,[a^{+} + a^{-}] = [b^{+} + b^{-}] \tag{C.3.1}$$

$$[Y^{I}]\,[a^{+} - a^{-}] = [H^{T}]\,[Y^{II}]\,[b^{+} - b^{-}]\ . \tag{C.4.1}$$

C.3.1 is solved for $[b^{+}]$:

$$[b^{+}] = [H]\,[a^{+} - a^{-}] - [b^{-}]\ .$$

Substituting $[b^{+}]$ into C.4.1:

$$[Y^{I}+H^{T}Y^{II}H]\,[a^{-}] = [Y^{I}-H^{T}Y^{II}H]\,[a^{+}] + 2[H^{T}Y^{II}]\,[b^{-}]\ .$$

Whence,

$$\begin{aligned}[a^{-}] = {} & [Y^{I}+H^{T}Y^{II}H]^{-1}\,[Y^{I}-H^{T}Y^{II}H]\,[a^{+}] \\ & + 2[Y^{I}+H^{T}Y^{II}H]^{-1}\,[H^{T}Y^{II}][b^{-}]\ .\end{aligned} \tag{C.5}$$

Likewise, C.4.1 may be solved for $[a^{-}]$ and this substituted into C.3.1 to yield:

$$\begin{aligned}[b^{+}] = {} & [I+HY^{I^{-1}}H^{T}Y^{II}]^{-1}\ 2[H][a^{+}] \\ & - [I+HY^{I^{-1}}H^{T}Y^{II}]^{-1}\,[I-HY^{I^{-1}}H^{T}Y^{II}][b^{-}]\ .\end{aligned} \tag{C.6}$$

But from standard scattering matrix notation with the values denoted as in Fig. II-3, we can also write:

$$\begin{bmatrix} a^- \\ b^+ \end{bmatrix} = \begin{bmatrix} S_{11} & S_{12} \\ S_{21} & S_{22} \end{bmatrix} \begin{bmatrix} a^+ \\ b^- \end{bmatrix}$$

or,

$$\begin{aligned} [a^-] &= [S_{11}][a^+] + [S_{12}][b^-] \,. \\ [b^+] &= [S_{21}][a^+] + [S_{22}][b^-] \,. \end{aligned} \qquad (C.7)$$

By comparing C.5 and C.6 with C.7, it is clear that:

$$\begin{aligned} [S_{11}] &= [Y^I + H^T Y^{II} H]^{-1} [Y^I - H^T Y^{II} H] \\ [S_{12}] &= 2[Y^I + H^T Y^{II} H]^{-1} \, [H^T Y^{II}] = [I - S_{11}] H^T \\ [S_{21}] &= 2[I + H[Y^I]^{-1} H^T Y^{II}]^{-1} \, [H] = H[I + S_{11}] \\ [S_{22}] &= [I + H{Y^I}^{-1} H^T Y^{II}]^{-1} \, [I - H{Y^I}^{-1} H^T Y^{II}] = -H[S_{11}]H^T \,. \end{aligned} \qquad (C.8)$$

APPENDIX D

SCATTERING MATRIX FOR A FINITE LENGTH SEPTUM

A generalized scattering matrix technique in a manner similar to that of Shih in [Ref. 3] is applied to obtain the two port scattering matrix for the finite septum.

Consider a TE_{mo} -type wave incident from Region I at the junction A. The field at this junction is comprised of the vector sum of all the eigenmodes in each region. Some of the energy will be reflected at the boundary, propagating in (ϕ_m) modal fields in the minus Z direction. The remainder of the energy will be transmitted into Region II in (ψ_p) modal fields in the positive Z direction. After traveling a distance D, the transmitted modes encounter the second junction, B, where again some energy is reflected, and some transmitted. Multiple reflections of the modes between junctions A and B is inherently accounted for in the matrix manipulations which yield the scattering matrix for the finite septum.

In C a single junction was analyzed as a two-port scattering matrix, $[S_A]$. Each of the four elements of this scattering matrix, $[S_{A11}]$, $[S_{A12}]$, $[S_{A21}]$, and $[S_{A22}]$, is a matrix of infinite dimensions, corresponding to the infinite set of eigenmodes in both regions (equation C.8).

The junction B is identical to A, except for orientation. It may be shown, therefore, that the scattering matrix for

the isolated junction B is related to the isolated junction at A by the following:

$$[S_{A11}] = [S_{B22}]$$

$$[S_{A12}] = [S_{B21}] \ .$$

The effects of the wave propagating (for propagating modes) or attenuating (for evanescent modes) along the strip length are accounted for by a transmission matrix, $[T_D]$, defined as:

$$[T_D] = \begin{bmatrix} [I] & [0] \\ & \\ [0] & [T] \end{bmatrix}$$

where [I] is the identity matrix, [0] is the null matrix, and [T] is a diagonal matrix of infinite size. The diagonal elements of [T] are:

$$T_{ii} = e^{-\gamma_{ii} D} \ .$$

The combined effect of the single junction A followed by the transmission along the strip for a distance D is given by the scattering matrix $[S'_A]$.

$$[S'_A] = [T_D]\,[S_A]\,[T_D]$$

Finally, the net effect of the finite septum is determined as follows.

$$a^- = S'_{A11}\, a^+ + S'_{A12}\, b^+ \tag{D.1}$$

$$b^- = S'_{A21}\, a^+ + S'_{A22}\, b^+ \tag{D.2}$$

$$c^- = S_{B11}\, c^+ + S_{B12}\, d^+ \tag{D.3}$$

$$d^- = S_{B21}\, c^+ + S_{B22}\, d^+ \tag{D.4}$$

$$b^+ = c^- \tag{D.5}$$

$$c^+ = b^- \tag{D.6}$$

We define an equivalent matrix for the finite septum, $[S_E]$, by:

$$a^- = S_{E11}\, a^+ + S_{E12}\, d^+ \tag{D.7}$$

$$d^- = S_{E21}\, a^+ + S_{E22}\, d^+ \;. \tag{D.8}$$

With the equalities given in equations D.5 and D.6, we substitute equation D.2 into D.3 to yield:

$$d^- = [S'_{A21}][I - S_{B22}\, S'_{A11}]^{-1}\ [S_{B21}]\ a^+$$

$$+ [S'_{A22}][I - S_{B22}\, S'_{A11}]^{-1}\ [S_{B22}\, S'_{A12}] + S'_{A22}]d^+ . \tag{D.9}$$

Likewise, we substitute equation D.4 into D.1 to yield:

$$a^- = [S'_{A11} + S'_{A12}[I - S_{B11}\, S'_{A22}]^{-1}\ [S_{B11}\, S'_{A21}]]$$

$$+ [S'_{A12}][I - S_{B11}\, S'_{A22}]^{-1}\ [S_{B12}]\ d^+ \ . \tag{D.10}$$

The matrices which are the elements of the equivalent scattering matrix may be written down by simply comparing equations D.9 and D.10 with equations D.7 and D.8.

$$S_{E11} = [S'_{A11}]+[S'_{A12}][I - S_{B11}\, S'_{A22}]^{-1}[S_{B11}\, S'_{A21}]]$$

$$S_{E12} = [S'_{A12}][I - S_{B11}\, S'_{A22}]^{-1}[S_{B12}]$$

$$S_{E21} = [S'_{A21}][I - S_{B22}\, S'_{A11}]^{-1}[S_{B21}]$$

$$S_{E22} = [S'_{A21}][I - S_{B22}\ S'_{A11}]^{-1}\ [S_{B22}\ S'_{A12}]+[S'_{A22}]\ . \qquad \text{(D.11)}$$

APPENDIX E

CASCADING SEVERAL FINITE LENGTH SEPTA

The fin-line filter is simply a series of finite length septa separated by transmission line sections. The net effect of the entire filter structure may be represented in a single "total" scattering matrix which accounts for the combined effects of each septa/transmission line section. This total scattering matrix is obtained by combining each septum equivalent matrix in a manner precisely analogous to that used in D to develop the equivalent matrix for a finite septum. That is, in D, expressions for the net effect of two discontinuities separated by a transmission line section were obtained (equation D.11). It is now necessary to express the net effect of two septa separated by a transmission line section. Consequently, the equivalent scattering matrix of two separated septa may be found by use of the equation D.11, with the appropriate scattering matrices for the septa substituted for the junction scattering matrix. More than two septa are cascaded by repeated application of D.11. Due care must be exercised to assure that the propagation numbers used in the transmission matrix correspond to the appropriate wave number and region of waveguide propagation.

APPENDIX F

COMPUTER AIDED DESIGN PROGRAM

```
C FILTER DESIGN (FILDES) FORTRAN PROGRAM
C
C BY KEITH B. ALEXANDER
C AND STEVEN R. HAMEL
C
C THE PURPOSE OF THIS PROGRAM IS TO DEVELOP FILTERS FOR WAVEGUIDE
C    STRUCTURES AND SIMULATE THE CHARACTERISTIC OF THIS FILTER THRU
C    A SPECIFIED FREQUENCY RANGE.  THE USER HAS THE CHOICE OF EITHER
C    DESIGNING THE FILTER AND INPUTTING THE NECESSARY DIMENSIONS OR
C    THE USER CAN INPUT THE CHARACTERISTICS THAT THE FILTER SHOULD
C    HAVE AND THE COMPUTER WILL DESIGN THE FILTER.  IN BOTH CASES THE
C    COMPUTER WILL OUTPUT THE CHARACTERISTICS OF THE FILTER THROUGH
C    A USER DESIGNATED FREQUENCY RANGE.
C
C THE USER THEREFORE HAS TWO OPTIONS IN THIS PROGRAM TO DEVELOP A
C    FILTER USING THIS PROGRAM OR TO INPUT HIS OWN FILTER DESIGN.
C    IN EITHER CASE IT IS NORMALLY EASIER TO USE A PRECANNED INPUT
C    FILE RATHER THAN ENTERING IN EACH VARIABLE INTO THE COMPUTER.
C
C TO DEVELOP A CANNED INPUT FILE FOR THE COMPUTER AIDED DESIGN OF
C    A FILTER ONE WOULD INPUT A FILE AS SHOWN BELOW:
C
C  FIL1 FILE (OR ANY NAME THE USER CHOOSES AND CAN REMEMBER)
C
C     1
C     10
C     1.143 .50663
C     1.00 1.6197
C     9.00 10.00
C     10.5 15.0
C     .50
C     8.00
C     100.0 41
C     0.50 12.0
C     -30.00  10.0
C     0.00
C
C  EXPLANATION OF PRECANNED FILE
C
C    DESIGN OPTION (1 = COMPUTER DESIGN, 0 = OWN DESIGN)
C    FILTER NUMBER FOR OUTPUT GRAPH
C    HALF WAVEGUIDE WIDTH AND DISTANCE FROM CENTER TO EDGE OF FILTER (CM)
C    DIELECTRIC CONSTANTS: INNER REGION; OUTER REGION
C    FREQUENCY PASSBAND OF FILTER IN GHZ BEGINNING AND END
C    PASSBAND CHARACTERISTIC IN GHZ AND AMOUNT OF LOSS IN DB
C    RIPPLE ACROSS THE PASSBAND IN DB
C    BEGINNING POINT IN GHZ FOR GRAPH OUTPUT
C    FREQ INTERVAL FOR POINTS AND NUMBER OF POINTS TO GRAPH
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C     GRAPH TICK MARKS IN GHZ AND END POINT IN GHZ                      THE00490
C     DB LOW POINT AND INTERVAL FOR GRAPH                               THE00500
C     DB HIGH POINT FOR GRAPH                                           THE00510
C                                                                       THE00520
C                                                                       THE00530
C   PRECANNED FILE FOR YOUR OWN FILTER DESIGN                           THE00540
C                                                                       THE00550
C     DES1 FILE (OR ANY NAME THE USER CAN REMEMBER)                     THE00560
C                                                                       THE00570
C     0                                                                 THE00580
C     10                                                                THE00590
C     3                                                                 THE00600
C     0.247     0.444     0.247                                         THE00610
C     2.1533    2.1533                                                  THE00620
C     1.143     .508                                                    THE00630
C     1.00      2.22                                                    THE00640
C     8.0                                                               THE00650
C     100.0     41                                                      THE00660
C     .50       12.0                                                    THE00670
C     -30.00   10.00                                                    THE00680
C      0.00                                                             THE00690
C                                                                       THE00700
C   EXPLANATION FOR PRECANNED FILE                                      THE00710
C                                                                       THE00720
C     DESIGN OPTION (0 = OWN DESIGN; 1 = COMPUTER AIDED DESIGN)         THE00730
C     NUMBER OF STRIPS IN YOUR DESIGN                                   THE00740
C     FILTER NUMBER FOR OUTPUT GRAPH                                    THE00750
C     STRIP WIDTHS (CM)                                                 THE00760
C     DISTANCE BETWEEN STRIPS (RESONATOR) WIDTHS (CM)                   THE00770
C     HALF WAVEGUIDE WIDTH AND DISTANCE FROM CENTER TO EDGE OF FILTER (CM)THE00780
C     DIELECTRIC CONSTANTS IN MIDDLE REGION AND OUTER REGION            THE00790
C     FREQUENCY START POINT OF GRAPH IN GHZ                             THE00800
C     FREQUENCY INTERVAL BETWEEN SIMULATION POINTS (MHZ) AND NO. OF POINTSTHE00810
C     FREQ INT FOR GRAPH TICK MARKS (GHZ) AND END POINT OF GRAPH (GHZ)  THE00820
C     DB LOW POINT AND INTERVAL FOR GRAPH                               THE00830
C     DB HIGH POINT FOR GRAPH                                           THE00840
C                                                                       THE00850
C   USE OF PROGRAM                                                      THE00860
C     (NOTE: THIS PROGRAM SHOULD BE COMPILED WITH THE H COMPILER)       THE00870
C     TO USE THIS PROGRAM WITH A PRECANNED FILE PROCEED AS FOLLOWS:     THE00880
C                                                                       THE00890
C     ENTER: DEFINE STORAGE 1M                                          THE00900
C     ENTER: I CMS                                                      THE00910
C     ENTER: GLOBAL TXTLIB FORTMOD2 MOD2EEH IMSLDP                      THE00920
C     ENTER: FILEDEF 05 DISK FIL1 FILE                                  THE00930
C     (OR ENTER): FILEDEF 05 DISK DES1 FILE                             THE00940
C     ENTER: FILEDEF 06 DISK RESULT FILE                                THE00950
C     ENTER: DISSPLA FILDES1                                            THE00960
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C
C THE RESULTS OF YOUR PROGRAM WILL BE IN ' RESULT FILE '
C TO GET A GRAPH OF THE OUTPUT:
C
C   ENTER: DISSPOP
C
C AND FOLLOW THE NORMAL IBM PROCEDURE FOR GRAPH OUTPUTS.
C
C SUBROUTINES USED IN THIS PROGRAM
C
C  GETDAT - USED TO GET NECESSARY DATA FROM THE USER WHEN
C     THE USER IS USING THE COMPUTER AIDED DESIGN OPTION.
C
C  ENTDAT - USED TO GET NECESSARY DATA FROM THE USER WHEN
C     THE USER HAS HIS OWN FILTER TO TEST.
C
C  DESIGN - USED TO DESIGN THE FILTER BASED ON USER REQUIREMENTS.
C
C  LEVY - FILTER SYNTHESIS SUBROUTINE USED TO DESIGN THE FILTER.
C
C  TREGAM - USED TO RETURN FREQUENCIES BASED ON INPUT WAVELENGTHS.
C
C  ZROCRS - USED TO FIND THE ZERO POINT OF A ROOT BASED ON BISECTION.
C
C  BETAFI - FINDS THE BETA VALUE FOR A DESIGNATED FREQUENCY.
C
C  COEFF - USED TO FIND THE REFLECTION COEFFICIENTS FOR DIFFERENT
C     MODES FOR A DESIGNATED FILTER DESIGN.
C
C  DEC - USED AS A SUBPROGRAM TO 'COEFF' TO HELP FIND THE REFLECTION
C     COEFFICIENTS FOR EACH MODE.
C
C  FILTER - PROGRAM USED TO DEVELOP THE S-MATRIXES BASED ON GIVEN
C     FREQUENCIES.
C
C  BUILD - USED TO DEVELOP SEPARATOR AND RESONATOR WIDTHS.
C
C  ROOT - USED AS A SUBPROGRAM TO 'BUILD' TO FIND SEPARATOR AND
C     RESONATOR WIDTHS.
C
C  PROPAG - USED TO DEVELOP THE PROPAGATION NUMBERS FOR EACH MODE.
C
C  SMATRI - USED TO DEVELOP THE S-MATRIX FOR EACH FREQUENCY.
C
C  MATWRI - USED TO OUTPUT THE VALUES OF MATRIXES.
C
C  CMMUL - COMPLEX MATRIX MULTIPLICATION SUBROUTINE.
C
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C  CMSUM - COMPLEX MATRIX SUMMATION SUBROUTINE.                           THE01450
C                                                                         THE01460
C  PACMAN - USED TO CONDENSE THE CRITICAL ELEMENTS OF THE 30 BY 30        THE01470
C     S-MATRIX INTO 5 BY 5 MATRICES.                                      THE01480
C                                                                         THE01490
C  CMSUB - COMPLEX MATRIX SUBTRACTION SUBROUTINE.                         THE01500
C                                                                         THE01510
C  CASCAD - SUBROUTINE USED TO CASCADE THE S-EQUIVALENT MATRICES DOWN     THE01520
C     THE ENTIRE LENGTH OF A FILTER.                                      THE01530
C                                                                         THE01540
C  TRANSM - SUBROUTINE THAT DEVELOPS THE TRANSMISSION EFFECT ON THE       THE01550
C     S-PARAMETERS FOR A GIVEN STRIP OR SEPARATOR LENGTH.                 THE01560
C                                                                         THE01570
C  DSUM - USED TO SUM EQUIVALENT S-MATRIX PARAMETERS TOGETHER.            THE01580
C                                                                         THE01590
C  CMRNMU - COMPLEX MATRIX REAL NUMBER MULTIPLICATION.                    THE01600
C                                                                         THE01610
C  CASCA - USED TO DEVELOP THE S-MATRIX FOR AN ENTIRE STRIP, OR COLLECTITHE01620
C     OF STRIPS, DEPENDING ON INPUT PARAMETERS.                           THE01630
C                                                                         THE01640
C  STEP3 - USED AS A SUBPROGRAM OF A FUNCTION TO DEVELOP THE S-MATRIX     THE01650
C     PARAMETERS FOR A GIVEN STRIP.                                       THE01660
C                                                                         THE01670
C  STRIWI - USED TO DEVELOP THE ACTUAL STRIP WIDTHS AND RESONATOR WIDTHSTHE01680
C                                                                         THE01690
C  LEQT1C - LINEAR EQUATION SOLVER, FROM IBM LIBRARY.                     THE01700
C                                                                         THE01710
C                                                                         THE01720
C FUNCTIONS USED IN THIS PROGRAM:                                         THE01730
C                                                                         THE01740
C  TCHEBY - USED TO RETURN TCHEBYSHEV COEFFICIENTS AS A SUBPROGRAM OF     THE01750
C     LEVY, IN FILTER DESIGN.                                             THE01760
C                                                                         THE01770
C  FCT1 - FINDS THE ZERO POINT FOR FREQUENCY CROSSINGS.                   THE01780
C                                                                         THE01790
C  SF1 - USED TO FIND S-MATRIX COEFFICIENTS FOR VARIOUS STRIP WIDTHS.     THE01800
C                                                                         THE01810
C                                                                         THE01820
C  SUBROUTINES DESIGN, LEVY, ZROCRS, COEFF, DEC, FILTER, BUILD, ROOT,     THE01830
C     CASCA, STEP3, AND THE FUNCTIONS ARE BASED ON ORIGINAL WORK DONE     THE01840
C     BY DR. YI-CHI SHIH IN HIS DOCTORAL DISSERTATION FOR FINLINE         THE01850
C     STRUCTURES IN WAVEGUIDES.                                           THE01860
C                                                                         THE01870
C                                                                         THE01880
C VARIABLES USED THROUGHOUT THE ENTIRE PROGRAM                            THE01890
C                                                                         THE01900
C  FREQ    FREQUENCY IN GIGAHERTZ                                         THE01910
C  FRQ     FREQUENCY IN GIGAHERTZ                                         THE01920
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C   FRESTE   NUMBER OF FREQUENCY STEPS FOR SIMULATION                         THE01930
C   FRQINT   FREQUENCY INTERVAL IN MEGAHERTZ FOR OUTPUT SIMULATION            THE01940
C   FRQEND   END FREQUENCY IN GIGAHERTZ FOR GRAPH                             THE01950
C   FREINT   FREQUENCY INTERVAL FOR GRAPH TICK MARKS                          THE01960
C   TEMP     TEMPORARY VARIABLE                                               THE01970
C   A        HALF OF THE WAVEGUIDE WIDTH IN CENTIMETERS                       THE01980
C   C        DISTANCE FROM THE EDGE OF THE FILTER TO THE WAVEGUIDE            THE01990
C            WALL IN CENTIMETERS                                              THE02000
C   D        DISTANCE FROM THE CENTER OF THE WAVEGUIDE TO THE EDGE            THE02010
C            OF THE FILTER IN CENTIMETERS                                     THE02020
C   NSTRIP   NUMBER OF CONDUCTING STRIPS ON THE DIELECTRIC SLAB               THE02030
C   NOS      NUMBER OF CONDUCTING STRIPS                                      THE02040
C   NOR      NUMBER OF RESONATORS                                             THE02050
C   COSTWI   CONDUCTING STRIP WIDTH (VECTOR)                                  THE02060
C   DIBECS   DISTANCE BETWEEN CONDUCTING STRIPS (VECTOR)                      THE02070
C   ERU      RELATIVE DIELECTRIC CONSTANT FOR THE UPPER REGION                THE02080
C   ERL      RELATIVE DIELECTRIC CONSTANT FOR THE LOWER REGION                THE02090
C   UO       MAGNETIC PERMEABILITY (CONSTANT)                                 THE02100
C   W        FREQUENCY IN RADIANS                                             THE02110
C   LAM      FREESPACE WAVELENGTH                                             THE02120
C   PI       CONSTANT PI                                                      THE02130
C   NMODES   NUMBER OF MODES THAT THE USER WANTS TO TRY (UP TO 30)            THE02140
C   NPMODE   NUMBER OF MODES THAT ARE USED IN THE CENTER REGION               THE02150
C   T1       TEMPORARY VARIABLE                                               THE02160
C   X1       VARIABLE FOR PROPAGATION TERMS                                   THE02170
C   T2       TEMPORARY VARIABLE                                               THE02180
C   X2       VARIABLE FOR PROPAGATION TERMS                                   THE02190
C   TREQ1    NUMERICAL VALUE OF A TRANSCENDENTAL EQUATION USED TO DETERMINTHE02200
C            THE WAVE NUMBERS IN THE VARIOUS REQIONS OF THE WAVEGUIDE         THE02210
C   TREQ2    SAME, BUT EVALUATED AT X2                                        THE02220
C   ERRREQ   PRECISION REQUIREMENTS FOR DETERMINING THE WAVE NUMBERS          THE02230
C   X3       TEMPORARY VARIABLE                                               THE02240
C   KA       RESULTANT VECTOR CONTAINING WAVE NUMBERS IN REGION 1 (LOWER)     THE02250
C   KD       RESULTANT VECTOR CONTAINING WAVE NUMBERS IN REGION 1 (UPPER)     THE02260
C   KE       RESULTANT VECTOR CONTAINING WAVE NUMBERS IN REGION 2 (LOWER &THE02270
C            UPPER)                                                           THE02280
C   KKKD     TEMPORARY VARIABLE                                               THE02290
C   KKKA     TEMPORARY VARIABLE                                               THE02300
C   NPMODE   NUMBER OF MODES THAT ARE CONSIDERED IN REGION 2 UPPER            THE02310
C   Y1       IMPEDANCE VECTOR FOR REGION 1                                    THE02320
C   Y2       IMPEDANCE VECTOR FOR REGION 2                                    THE02330
C   GAMMA1   PROPAGATION VECTOR FOR REGION 1                                  THE02340
C   GAMMA2   PROPAGATION VECTOR FOR REGION 2                                  THE02350
C   H        SPACE MAPPING MATRIX                                             THE02360
C   YREG1    IMPEDANCE MATRIX FOR REGION 1                                    THE02370
C   YREG2    IMPEDANCE MATRIX FOR REGION 2                                    THE02380
C   S11      SCATTERING PARAMETER MATRIX                                      THE02390
C   S12      SCATTERING PARAMETER MATRIX                                      THE02400
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C     S21      SCATTERING PARAMETER MATRIX                                      THE02410
C     S22      SCATTERING PARAMETER MATRIX                                      THE02420
C     ALPHA    TEMPORARY VARIABLE USED TO DEFINE H                              THE02430
C     DELTA    TEMPORARY VARIABLE USED TO DEFINE H                              THE02440
C     X        TEMPORARY MATRIX USED TO MULTIPLY TWO MATRICES                   THE02450
C     Y        TEMPORARY MATRIX USED TO MULTIPLY TWO MATRICES                   THE02460
C     AXY      OUTPUT OF MATRIX MULTIPLICATION                                  THE02470
C     N        SUMMATION INDEX FOR MATRIX MULTIPLICATION                        THE02480
C     XXX      TEMPORARY MATRIX USED IN MATRIX SUBTRACTION                      THE02490
C     YYY      TEMPORARY MATRIX USED IN MATRIX SUBTRACTION                      THE02500
C     CC       OUTPUT MATRIX FOR MATRIX SUBTRACTION                             THE02510
C     NNN      SUMMATION INDEX FOR MATRIX SUBTRACTION                           THE02520
C     XX       TEMPORARY MATRIX FOR MATRIX ADDITION                             THE02530
C     YY       TEMPORARY MATRIX FOR MATRIX ADDITION                             THE02540
C     B        OUTPUT MATRIX FOR MATRIX ADDITION                                THE02550
C     NN       SUMMATION INDEX FOR MATRIX SUBTRACTION                           THE02560
C     ST       TEMPORARY MATRICES USED IN CASCAD SUBROUTINE                     THE02570
C     SE       TEMPORARY MATRICES USED IN CASCAD SUBROUTINE                     THE02580
C     SS       TEMPORARY MATRICES USED IN CASCAD SUBROUTINE                     THE02590
C     STE      TEMPORARY MATRICES USED IN TRANSM SUBROUTINE                     THE02600
C     X12      TRANSMISSION MATRIX FOR S12                                      THE02610
C     Y21      TRANSMISSION MATRIX FOR S21                                      THE02620
C     Z22      TRANSMISSION MATRIX FOR S22                                      THE02630
C     G        VECTOR USED TO PASS GAMMA VECTORS FOR ALL REGIONS                THE02640
C     Z        VARIABLE USED TO PASS STRIP WIDTHS AND DISTANCES                 THE02650
C     N        SUMMATION INDEX                                                  THE02660
C     SA       TEMPORARY MATRICES USED FOR NETWORK COMBINATION OF MATRICES      THE02670
C     SC       TEMPORARY MATRICES USED FOR NETWORK COMBINATION OF MATRICES      THE02680
C     DEN      IDENTITY MATRIX                                                  THE02690
C     MM       SUMMATION INDEX FOR NETWORK THEORY COMBINATIONS                  THE02700
C                                                                               THE02710
      COMPLEX *16 SM11(5,5),SM12(5,5),SM21(5,5),SM22(5,5)                       THE02720
      COMPLEX *16 S11(30,30),S12(30,30),S21(30,30),S22(30,30)                   THE02730
      COMPLEX *16 SE11(30,30),SE12(30,30),SE21(30,30),SE22(30,30)               THE02740
      COMPLEX *16 ST11(30,30),ST12(30,30),ST21(30,30),ST22(30,30)               THE02750
      COMPLEX *16 SS11(5,5),SS12(5,5),SS21(5,5),SS22(5,5)                       THE02760
      COMPLEX *16 KA(30),KD(30),KE(30),Y1(30),Y2(30)                            THE02770
      COMPLEX *16 GAMMA1(30),GAMMA2(30),B(30,30),CC(30,30)                      THE02780
      COMPLEX *16 X(30,30),Y(30,30),Z(30,30),AXY(30,30)                         THE02790
      COMPLEX *16 XXX(30,30),YYY(30,30),ZZZ(30,30)                              THE02800
      COMPLEX *16 XX(30,30),YY(30,30),ZZ(30,30)                                 THE02810
      COMPLEX *16 XY(30,30),RM(30,30),SB1(5),SB2(5)                             THE02820
      REAL *8 ERU,ERL,U0,PI,W,D,LAM,A,C,COSTWI(20),DIBECS(19)                   THE02830
      REAL *8 FREINT,DD(20),WW(20),XDB,RDB,YLOW,YSTEP,YHIGH                     THE02840
      REAL *8 F1,F2,FR,FREQ,F0,S0,RH,COE(20),TEM,FRQ,FRQINT,FRQEND              THE02850
      REAL PLCTX(500),PLOTY(500)                                                THE02860
      INTEGER NMODES,NPMODE,NSTRIP,FRESTE,WHIWAY,FILNO                          THE02870
C                                                                               THE02880
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```
C FIRST GET INFORMATICN FROM THE USER
C
      WRITE(6,11)
   11 FORMAT(' ENTER 1 IF YOU WANT THE COMPUTER TO DESIGN AND TEST ',/,
     8' A FILTER FOR YOU OR "0" IF YOU WANT TO ENTER YOUR OWN DESIGN. ')
   12 READ(5,*) WHIWAY
      IF(WHIWAY.EQ.1) GOTO 14
      CALL ENTDAT(NOS,NOR,COSTWI,DIBECS,A,D,ERU,ERL,FREQ,FRQINT,FRQEND,
     8  PI,FRESTE,C,NMODES,NPMODE,FREINT,FILNO,YLOW,YSTEP,YHIGH)
      NSTRIP = NOS
      GOTO 15
   14 CALL GETDAT(A,D,ERL,ERU,F1,F2,FR,RDB,XDB,FREQ,FREINT,FRESTE,
     8PI,C,NMODES,NPMODE,FRQINT,FRQEND,FILNO,YLOW,YSTEP,YHIGH)
C
C NOW CALCULATE THE NUMBER OF STRIPS FOR THE REQUIRED FILTER
C
      CALL DESIGN(DD,WW,F1,F2,FR,XDB,RDB,ERU,ERL,FO,SO,RH,COE,A,D,PI,
     8     NMODES,NPMODE,NOS,NOR)
      CALL STRIWI(NOS,NOR,DD,WW,COSTWI,DIBECS,NSTRIP)
   15 FRQ = FREQ
      WRITE (6,2143)NOS,NOR
 2143 FORMAT(//,' HERE ARE THE ',I3,' CONDUCTING STRIP WIDTHS ',/,
     8' AND THE ',I3,' RESONATOR WIDTHS ',//)
      DO 1567 JI=1,NSTRIP
         WRITE(6,1578) COSTWI(JI),DIBECS(JI),NOS,NOR
 1578 FORMAT(2F15.8,2I3)
 1567 CONTINUE
      WRITE(6,1599)
 1599 FORMAT(' LISTED BELOW IS THE POWER TRANSMITTED THRU YOUR ',/,
     8' FILTER FOR EACH RESPECTIVE FREQUENCY POINT. '//)
      DO 20 I = 1,FRESTE
         LAM = 29.97925/FREQ
         CALL TREQ(PI,A,LAM,NMODES,D,KA,KD,KE,NPMODE,ERU,ERL)
C
C GET THE PROPAGATION TERMS FOR EACH REGION
C
         W = 2.0*PI*FREQ
         UO = 4.0*PI
C
         CALL PROPAG(KA,KE,GAMMA1,Y1,GAMMA2,Y2,PI,LAM,ERU,ERL,W,UO,
     8           NMODES,NPMODE)
C
C DEVELOP THE SCATTERING MATRIX FOR THE FIRST STRIP EDGE
C
         CALL SMATRI(SM11,SM12,SM21,SM22,KA,KD,KE,A,D,NMODES,Y1,Y2
     8     ,NPMODE,GAMMA2,SB1,SB2,GAMMA1)
C
C NOW CASCADE THE MATRIX TO GET THE FILTER CHARACTERISTICS
```

```
C
      CALL CASCAD(SM11,SM12,SM21,SM22,SB1,SB2,COSTWI,DIBECS,
     8 NMODES,NSTRIP,SS11,SS12,SS21,SS22)
C
      PLOTY(I) = 20.0*DLOG10(CDABS(SS21(1,1)))
      PLOTX(I) = FREQ
      TEM = (CDABS(SS11(1,1)))**2.0 +(CDABS(SS12(1,1)))**2.0
      FREQ = FREQ + (FREINT/1000.0)
      WRITE(6,322) PLOTY(I),PLOTX(I),TEM
  322 FORMAT(' DB LOSS, FREQ IN GHZ, ENERGY CHECK ',F12.6 ,4X,F8.4,4X,
     8F6.4)
 20   CONTINUE
      CALL COMPRS
      CALL MEDBUF
      CALL NOCHEK
      CALL BLOWUP(1.0)
      CALL PAGE(11.0, 8.5)
      CALL PHYSOR (2.25,2.50)
      CALL GRACE(0.0)
      CALL AREA2D(7.25,4.25)
      CALL XNAME('FREQUENCY IN GIGAHERTZ$', 100)
      CALL YNAME('THRU POWER IN DB$', 100)
      CALL GRAF(FRQ,FRQINT,FRQEND,YLOW,YSTEP,YHIGH)
      CALL CURVE(PLOTX,PLOTY,FRESTE,0)
      CALL ENDGR(0)
      CALL PHYSOR(1.5,1.25)
      CALL AREA2D(8.5,6.0)
      CALL HEIGHT(.2)
      CALL SWISSM
      CALL MESSAG('FILTER $',100,1.4,0.30)
      CALL REALNO(FILNO,0,2.5,.30)
      CALL ENDPL(0)
      CALL DONEPL
      STOP
      END
C
C
C
      SUBROUTINE GETDAT(A,D,ERL,ERU,F1,F2,FR,RDB,XDB,FREQ,FREINT,FRESTE,
     8PI,C,NMODES,NPMODE,FRQINT,FRQEND,FILNO,YLOW,YSTEP,YHIGH)
C  THE PURPOSE OF THIS SUBROUTINE IS TO GET THE INFORMATION
C   FROM THE USER NECESSARY FOR THIS PROGRAM TO RUN.
C
C
      REAL *8 A,D,ERL,ERU,F1,F2,FR,RDB,XDB,FREQ,PI,C,FREINT
      REAL *8 FRQINT,FRQEND,YLOW,YSTEP,YHIGH,BP
      REAL MODE
      INTEGER FRESTE,NMODES,NPMODE,FILNO
```

```
C
C TELL USER THE PLRPOSE OF THIS PROGRAM AND NECESSARY GENERAL COMMENTS
C
      WRITE (6,300)
  300 FORMAT(' THIS IS A PROGRAM USED TO DESIGN FILTERS. ',/,
     8' YOU WILL BE PROMPTED FOR THE REQUIRED INPUTS. ')
C
      WRITE(6,3001)
 3001 FORMAT(' ENTER THE FILTER NUMBER FOR YOUR GRAPH. ')
      READ(5,*) FILNO
      WRITE(6,350) FILNO
  350 FORMAT(5X,I5,/)
C
      WRITE (6,301)
  301 FORMAT(' INPUT HALF OF THE WAVE GUIDE WIDTH ',/,
     8' AND DISTANCE FROM THE CENTER OF THE GUIDE TO SEPTUM EDGE. ')
      READ (5,*) A,D
      WRITE (6,351) A,D
  351 FORMAT(5X,F12.8,5X,F12.8,/)
C
      WRITE (6,302)
  302 FORMAT(' INPUT THE COEFFICIENTS FOR THE DIELECTRIC BETWEEN ',/,
     8' FIRST THE CENTER OF THE GUIDE AND SEPTUM EDGE; ',/,
     8' AND SECOND BETWEEN SEPTUM WALL AND WAVEGUIDE WALL ')
      READ (5,*) ERL,ERU
      WRITE(6,352) ERL,ERU
  352 FORMAT(5X,F12.8,5X,F12.8,/)
C
      NMODES = 30
C
C NOW TO GET THE REQUIREMENTS FOR THE FILTER
C
      WRITE (6,303)
  303 FORMAT(' NOW YOU WILL INPUT THE FILTER PARAMETERS ',/,
     8' ENTER THE BEGINNING AND END FREQUENCY FOR THE PASSBAND ',/,
     8' OF THE FILTER. ')
      READ (5,*) F1,F2
      WRITE(6,353) F1,F2
  353 FORMAT(5X,F12.8,5X,F12.8,/)
      BP = 2.0*(F2-F1)/(F1+F2)
      F1 = F1*(1.0 - BP*BP)
C
      WRITE (6,304)
  304 FORMAT(' NOW ENTER THE FREQUENCY AND DB DOWN FOR THE ',/,
     8' TAIL OF TFE FILTER ')
      READ (5,*) FR,RDB
      WRITE(6,354) FR,RDB
  354 FORMAT(5X,F12.8,5X,F12.8,/)
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C                                                                       THE04330
      WRITE (6,305)                                                     THE04340
  305 FORMAT(' NOW ENTER THE RIPPLE IN DB ON THE TOP OF THE PASSBAND. ')THE04350
      READ (5,*) XDB                                                    THE04360
      WRITE(6,355) XDB                                                  THE04370
  355 FORMAT(5X,F12.8,/)                                                THE04380
C                                                                       THE04390
      WRITE (6,306)                                                     THE04400
  306 FORMAT(' THE FINAL OUTPUT OF THIS PROGRAM IS A GRAPH. ',/,        THE04410
     8' ENTER THE BEGINNING POINT OF THE GRAPH IN GHZ ')                THE04420
      READ (5,*) FREQ                                                   THE04430
      WRITE(6,356) FREQ                                                 THE04440
  356 FORMAT(5X,F12.8,/)                                                THE04450
C                                                                       THE04460
      WRITE (6,307)                                                     THE04470
  307 FORMAT(' ENTER THE FREQUENCY INTERVAL IN MHZ AND ',/,             THE04480
     8' THE NUMBER OF STEPS THAT YOU WOULD LIKE ')                      THE04490
      READ(5,*) FREINT,FRESTE                                           THE04500
      WRITE(6,357) FREINT,FRESTE                                        THE04510
  357 FORMAT(5X,F12.8,5X,I5,/)                                          THE04520
C                                                                       THE04530
      WRITE (6,308)                                                     THE04540
  308 FORMAT(' ENTER THE INTERVAL MARKS FOR THE GRAPH ',/,              THE04550
     8' AND THE END POINT FOR THE GRAPH. ')                             THE04560
      READ(5,*) FRQINT,FRQEND                                           THE04570
      WRITE(6,358) FRQINT,FRQEND                                        THE04580
  358 FORMAT(5X,F12.8,5X,F12.8,/)                                       THE04590
C                                                                       THE04600
      WRITE (6,309)                                                     THE04610
  309 FORMAT(' ENTER THE YAXIS ZERO POINT AND TICK MARK INTERVALS ',/,  THE04620
     8' FOR THE GRAPH IN DB. ')                                         THE04630
      READ(5,*) YLOW, YSTEP                                             THE04640
      WRITE(6,359) YLOW, YSTEP                                          THE04650
  359 FORMAT(5X,F12.8,5X,F12.8,/)                                       THE04660
C                                                                       THE04670
      WRITE (6,310)                                                     THE04680
  310 FORMAT(' ENTER THE YAXIS HIGH POINT IN DB. ')                     THE04690
      READ(5,*) YHIGH                                                   THE04700
      WRITE(6,360) YHIGH                                                THE04710
  360 FORMAT(5X,F12.8,/)                                                THE04720
C                                                                       THE04730
C DEFINING SEVERAL CONSTANTS                                            THE04740
C                                                                       THE04750
      PI = 3.14159265                                                   THE04760
      C = A - D                                                         THE04770
C                                                                       THE04780
      MODE = (C/A)*(FLOAT(NMODES))                                      THE04790
      NPMODE = IFIX(MODE)                                               THE04800
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      IF((MODE-NPMODE).GT.0.5) NPMODE=NPMODE+1                          THE04810
C                                                                       THE04820
      RETURN                                                            THE04830
      END                                                               THE04840
C                                                                       THE04850
C                                                                       THE04860
      SUBROUTINE ENTDAT(NOS,NOR,COSTWI,DIBECS,A,D,ERU,ERL,FREQ,FRQINT,  THE04870
     8 FRQEND,PI,FRESTE,C,NMODES,NPMODE,FREINT,FILNO,YLOW,YSTEP,        THE04880
     8 YHIGH)                                                           THE04890
C                                                                       THE04900
      REAL *8 COSTWI(20),DIBECS(19),A,D,ERU,ERL,FREQ,FRQEND             THE04910
      REAL *8 PI,C,FREINT,FRQINT,YLOW,YSTEP,YHIGH                       THE04920
      REAL MODE                                                         THE04930
      INTEGER NOS,NOR,FRESTE,NMODES,NPMODE,FILNO                        THE04940
C                                                                       THE04950
      PI = 3.14159265                                                   THE04960
      WRITE(6,100)                                                      THE04970
  100 FORMAT(' THIS IS A PROGRAM USED TO TEST PRE-DESIGNED FILTERS. ',/,THE04980
     8' YOU WILL BE PROMPTED FOR REQUIRED INPUTS. ')                    THE04990
C                                                                       THE05000
      WRITE(6,3001)                                                     THE05010
 3001 FORMAT(' ENTER THE FILTER NUMBER FOR YOUR GRAPH. ')               THE05020
      READ(5,*) FILNO                                                   THE05030
      WRITE(6,150) FILNO                                                THE05040
  150 FORMAT(' FILTER ',I5,/)                                           THE05050
C                                                                       THE05060
      WRITE(6,101)                                                      THE05070
  101 FORMAT(' INPUT THE NUMBER OF STRIPS IN YOUR FILTER DESIGN. ')     THE05080
      READ(5,*) NCS                                                     THE05090
      NOR = NOS - 1                                                     THE05100
      WRITE(6,151) NOS,NOR                                              THE05110
  151 FORMAT(5X,' NOS = ',I5,5X,' NOR = ',I5,/)                         THE05120
C                                                                       THE05130
      WRITE(6,102)                                                      THE05140
  102 FORMAT(' ENTER THE STRIP WIDTHS IN CENTIMETERS. ')                THE05150
      DO 103 I = 1,NOS                                                  THE05160
         READ(5,*) COSTWI(I)                                            THE05170
         WRITE(6,153) I,COSTWI(I)                                       THE05180
  153 FORMAT(' STRIP NO ',I3,' = ',F12.8)                               THE05190
  103 CONTINUE                                                          THE05200
C                                                                       THE05210
      WRITE(6,104)                                                      THE05220
  104 FORMAT(' ENTER THE RESONATOR WIDTHS IN CENTIMETERS. ')            THE05230
      DO 105 J = 1,NOR                                                  THE05240
         READ(5,*) DIBECS(J)                                            THE05250
         WRITE(6,155) J,DIBECS(J)                                       THE05260
  155 FORMAT(' RESONATOR NO ',I3,' = ',F12.8)                           THE05270
  105 CONTINUE                                                          THE05280
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C
      WRITE(6,106)
  106 FORMAT(' INPUT HALF OF THE WAVEGUIDE WIDTH, CM, AND DISTANCE ',/,
     8' FROM THE CENTER OF THE WAVEGUIDE TO THE SEPTUM EDGE ,CM. ')
      READ(5,*) A,D
      WRITE(6,156) A,D
  156 FORMAT(5X,F12.8,5X,F12.8,/)
C
      C = A - D
C
      WRITE(6,107)
  107 FORMAT(' INPUT THE COEFFICIENTS FOR THE DIELECTRIC BETWEEN ',/,
     8' FIRST THE CENTER OF THE GUIDE AND SEPTUM EDGE; AND SECOND, ',/,
     8' BETWEEN THE SEPTUM WALL AND WAVEGUIDE WALL. ')
      READ(5,*) ERL,ERU
      WRITE(6,157) ERL,ERU
  157 FORMAT(5X,F12.8,5X,F12.8,/)
C
      WRITE(6,108)
  108 FORMAT(' THE FINAL OUTPUT OF THIS PROGRAM IS A GRAPH. ',/,
     8' ENTER THE BEGINNING POINT OF THE GRAPH IN GHZ ')
      READ (5,*) FREQ
      WRITE(6,158) FREQ
  158 FORMAT(5X,F12.8,/)
C
      WRITE (6,109)
  109 FORMAT(' ENTER THE FREQUENCY INTERVAL IN MHZ AND ',/,
     8' THE NUMBER OF STEPS THAT YOU WOULD LIKE ')
      READ(5,*) FREINT,FRESTE
      WRITE(6,159) FREINT,FRESTE
  159 FORMAT(5X,F12.8,5X,I5,/)
C
      WRITE (6,110)
  110 FORMAT(' ENTER THE INTERVAL MARKS FOR THE GRAPH ',/,
     8' AND THE END POINT FOR THE GRAPH. ')
      READ(5,*)FRCINT,FRQEND
      WRITE(6,160) FRQINT,FRQEND
  160 FORMAT(5X,F12.8,5X,F12.8,/)
C
      WRITE (6,309)
  309 FORMAT(' ENTER THE YAXIS ZERO POINT AND TICK MARK INTERVALS ',/,
     8' FOR THE GRAPH IN DB. ')
      READ(5,*) YLOW, YSTEP
      WRITE(6,359) YLOW, YSTEP
  359 FORMAT(5X,F12.8,5X,F12.8,/)
C
      WRITE (6,310)
  310 FORMAT(' ENTER THE YAXIS HIGH POINT IN DB. ')
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      READ(5,*) YHIGH                                                   THE05770
      WRITE(6,360) YHIGH                                                THE05780
  360 FORMAT(5X,F12.8,/)                                                THE05790
C                                                                       THE05800
      NMODES = 30                                                       THE05810
      MODE = (C/A)*(FLOAT(NMODES))                                      THE05820
      NPMODE = IFIX(MODE)                                               THE05830
      IF((MODE-NPMODE).GT.0.5) NPMODE=NPMODE+1                          THE05840
C                                                                       THE05850
      RETURN                                                            THE05860
      END                                                               THE05870
C                                                                       THE05880
C**ENTDAT                                                               THE05890
C**TREQ                                                                 THE05900
      SUBROUTINE TREQ(PI,A,LAM,NMODES,D,KA,KD,KE,NPMODE,ERU,ERL)        THE05910
C                                                                       THE05920
      COMPLEX *16 KA(30),KD(30),KE(30),J                                THE05930
      REAL *8 ERU,ERL,PI,A,LAM,T1,X1,T2,KXA,TREQ1,D,X2,TREQ2,ERRREQ,X3  THE05940
      REAL *8 KKKD,KKKA,TT,TREQ3,TTEMP,W,KXD                            THE05950
      REAL XTEMP                                                        THE05960
      INTEGER NMODES,NPMODE,NTEMP                                       THE05970
C                                                                       THE05980
      J = (0.0,1.0)                                                     THE05990
      IF(ERU.LT.ERL) GOTO 309                                           THE06000
         X1=(PI/(8.0*A))                                                THE06010
         T2 = (((2.0*PI)/LAM)**2.0)*(ERU-ERL)                           THE06020
         DO 350 I = 1,NMODES                                            THE06030
 351        T1 = X1**2.0                                                THE06040
            IF (T1.GT.T2) GOTO 361                                      THE06050
               KXA = ((T2-T1)**0.5)                                     THE06060
             TREQ1 =-X1*(DCOS(X1*(A-D)))*(DCOSH(KXA*D)) -               THE06070
     8          KXA*(DSINH(KXA*D))*(DSIN(X1*(A-D)))                     THE06080
               GOTO 362                                                 THE06090
 361        KXA = (T1-T2)**0.5                                          THE06100
            TREQ1 = KXA*DSIN(KXA*D)*DSIN(X1*(A-D)) -                    THE06110
     8              (X1*DCOS(KXA*D)*DCOS(X1*(A-D)))                     THE06120
 362        X2 = X1 + (PI/(8.0*A*ERU))                                  THE06130
            T1 = X2**2.0                                                THE06140
            IF(T1.GT.T2) GOTO 371                                       THE06150
               KXA = ((T2-T1)**0.5)                                     THE06160
             TREQ2 =-X2*(DCOS(X2*(A-D)))*(DCOSH(KXA*D)) -               THE06170
     8          KXA*(DSINH(KXA*D))*(DSIN(X2*(A-D)))                     THE06180
               GOTO 372                                                 THE06190
 371        KXA = ((T1-T2)**0.5)                                        THE06200
            TREQ2 = KXA*DSIN(KXA*D)*DSIN(X2*(A-D))-(X2*DCOS(KXA*D) *    THE06210
     8                    DCOS(X2*(A-D)))                               THE06220
 372        IF((TREQ1*TREQ2).LE.0.0) GOTO 380                           THE06230
               X1 = X2                                                  THE06240
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              GOTC 351                                          THE06250
 380       ERRREQ = (X2 * 0.00001)                              THE06260
           TTEMP = DABS((TREQ1+TREQ2)/2.0)                      THE06270
           IF(TTEMP.LE.ERRREQ) GOTO 381                         THE06280
              X3 = (X1+X2)/2.0                                  THE06290
              T1 = X3**2.0                                      THE06300
           IF(T1.GT.T2) GOTO 386                                THE06310
              KXA = ((T2-T1)**0.5)                              THE06320
            TREQ3 =-X3*(DCOS(X3*(A-D)))*(DCOSH(KXA*D)) -        THE06330
     8         KXA*(DSINH(KXA*D))*(DSIN(X3*(A-D)))              THE06340
              GOTC 385                                          THE06350
 386       KXA = (T1-T2)**0.5                                   THE06360
           TREQ3 = KXA*DSIN(KXA*D)*DSIN(X3*(A-D))-(X3*DCOS(KXA*D) *     THE06370
     8                  DCOS(X3*(A-D)))                         THE06380
 385       IF((TREQ1*TREQ3).LE.0.0) GOTO 387                    THE06390
              X1 = X3                                           THE06400
              TREQ1=TREQ3                                       THE06410
              GOTO 380                                          THE06420
 387       X2=X3                                                THE06430
           TREQ2=TREQ3                                          THE06440
           GOTO 380                                             THE06450
 381       T1 = (X1+X2)/2.0                                     THE06460
           KD(I) = T1                                           THE06470
           TT = T1**2                                           THE06480
           IF(TT.LT.T2) GOTO 388                                THE06490
              KXA = (TT - T2)**0.5                              THE06500
              KA(I) = KXA                                       THE06510
              GOTC 389                                          THE06520
 388       KXA = (T2 - TT)**0.5                                 THE06530
           KA(I) = J*KXA                                        THE06540
 389       X1 = X1 + (PI/(8.0*A))                               THE06550
 350       CONTINUE                                             THE06560
           GOTO 307                                             THE06570
 309  X1 =(PI/(8.0*A))                                          THE06580
      T2 =(((2.0*PI)/LAM)**2.0)*(ERL-ERU)                       THE06590
      DO 310 N = 1,NMODES                                       THE06600
 311     T1 = X1**2.0                                           THE06610
         IF(T1.GT.T2) GOTO 321                                  THE06620
            KXD = ((T2-T1)**0.5)                                THE06630
            TREQ1 = X1*(DSIN(X1*D))*(DSINH(KXD*(A-D))) -        THE06640
     8                  KXD*(DCOSH(KXD*(A-D)))*(DCOS(X1*D))     THE06650
            GOTO 322                                            THE06660
 321     KXD = (T1-T2)**0.5                                     THE06670
         TREQ1 = X1*DSIN(X1*D)*DSIN(KXD*(A-D)) - KXD*DCOS(X1*D) *       THE06680
     8           DCOS(KXD*(A-D))                                THE06690
 322     X2 = X1 + (PI/(8.0*A*ERL))                             THE06700
         T1 = X2**2.0                                           THE06710
         IF(T1.GT.T2) GOTO 331                                  THE06720
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          KXD = ((T2-T1)**0.5)                                          THE06730
          TREQ2 = X2*(DSIN(X2*D))*(DSINH(KXD*(A-D))) -                  THE06740
     8            KXD*(DCOSH(KXD*(A-D)))*(DCOS(X2*D))                   THE06750
          GOTO 332                                                      THE06760
 331    KXD = ((T1-T2)**0.5)                                            THE06770
        TREQ2 = X2*DSIN(X2*D) *DSIV(KXD*(A-D)) - KXD * DCOS(X2*D) *     THE06780
     8        DCCS(KXD*(A-D))                                           THE06790
 332    IF((TREQ1*TREQ2).LE.0.0) GOTO 330                               THE06800
          X1 = X2                                                       THE06810
          GOTO 311                                                      THE06820
 330    ERRREQ = (X2 * 0.00001)                                         THE06830
        TTEMP = DABS((TREQ1+TREQ2)/2.0)                                 THE06840
        IF(TTEMP.LE.ERRREQ) GOTO 341                                    THE06850
          X3 = (X1 + X2)/2.0                                            THE06860
         T1 = X3 ** 2.0                                                 THE06870
        IF (T1.GT.T2) GOTO 346                                          THE06880
          KXD = ((T2-T1)**0.5)                                          THE06890
          TREQ3 = X3*(DSIN(X3*D))*(DSINH(KXD*(A-D))) -                  THE06900
     8            KXD*(DCOSH(KXD*(A-D)))*(DCOS(X3*D))                   THE06910
          GOTO 345                                                      THE06920
 346    KXD = (T1-T2)**0.5                                              THE06930
        TREQ3 = X3*DSIN(X3*D)*DSIN(KXD*(A-D)) - KXD*DCOS(X3*D) *        THE06940
     8          DCOS(KXD*(A-D))                                         THE06950
 345    IF((TREQ1*TREQ3).LE.0.0) GOTO 347                               THE06960
          X1 = X3                                                       THE06970
          TREQ1 = TREQ3                                                 THE06980
          GCTO 330                                                      THE06990
 347    X2 = X3                                                         THE07000
        TREQ2 = TREQ3                                                   THE07010
        GOTO 330                                                        THE07020
 341    T1 = (X1+X2)/2.0                                                THE07030
        KA(N) = T1                                                      THE07040
        TT = T1**2                                                      THE07050
        IF(TT.LT.T2) GOTO 348                                           THE07060
          KXD = (TT -T2)**0.5                                           THE07070
          KD(N) = KXD                                                   THE07080
          GOTO 349                                                      THE07090
 348    KXD = (T2-TT)**0.5                                              THE07100
        KD(N) = J*KXD                                                   THE07110
 349    X1 = X1 + (PI/(8.0*A))                                          THE07120
 310  CONTINUE                                                          THE07130
      GOTO 307                                                          THE07140
C                                                                       THE07150
 307  DO 335 I = 1,NPMODE                                               THE07160
        KKKD = ((FLOAT(I)*PI)/(A-D))                                    THE07170
        KE(I) = KKKD                                                    THE07180
 335  CONTINUE                                                          THE07190
C                                                                       THE07200
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      NTEMP = NPMCDE + 1
      IF(NTEMP.GT.NMODES) GOTO 3335
      DO 334 I = NTEMP,NMODES
         KKKA = (((2.0*FLOAT(I-NTEMP+1))-1.0)*PI/(2*D))
         KE(I) = KKKA
 334  CONTINUE
 3335 NTEMP = NTEMP
      RETURN
      END
C**TREQ
C**PROPAG
      SUBROUTINE PROPAG(KA,KE,GAMMA1,Y1,GAMMA2,Y2,PI,LAM,ERU,ERL,W
     8                ,UO,NMODES,NPMODE)
C
      COMPLEX *16 WUJ,TEMP1,GAMMA1(30),GAMMA2(30),Y1(30),Y2(30),J
      COMPLEX *16 KA(30),KE(30)
      REAL *8 ERU,ERL,PI,LAM,W,UO
      INTEGER NMODES,NPMODE,NTEMP
C
      J = (0.0,1.0)
      WUJ = J*W*UO
      TEMP1 = ERL*(((2.0*PI)/LAM)**2.0)
      DO 451 I = 1,NMODES
         GAMMA1(I) = CDSQRT(KA(I)**2 - TEMP1)
         Y1(I) = GAMMA1(I)/WUJ
  451 CONTINUE
C
C FOR REGION 2, WE MUST COMBINE THE UPPER REGION, WITH THE LOWER REGION
C
      TEMP1 = (ERU*(((2.0*PI)/LAM)**2.0))
      DO 461 I = 1,NPMODE
         GAMMA2(I) = CDSQRT(KE(I)**2 - TEMP1)
         Y2(I) = GAMMA2(I)/WUJ
  461 CONTINUE
C
C THE NEXT PART ACDS THE REST OF REGION TWO VARIABLES INTO GAMMA2
C
      TEMP1 = (ERL*(((2.0*PI)/LAM)**2.))
      NTEMP = NPMCDE + 1
      IF(NTEMP.GT.NMODES) GOTO 4777
      DO 471 I = NTEMP,NMODES
         GAMMA2(I) = CDSQRT(KE(I)**2 - TEMP1)
         Y2(I) = GAMMA2(I)/WUJ
  471 CONTINUE
C
 4777 RETURN
      END
C**PROPAG
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C**SMATRI                                                               THE07690
      SUBROUTINE  SMATRI(SM11,SM12,SM21,SM22,KA,KD,KE,A,D,NMODES,Y1,Y2, THE07700
     8                  NPMODE,GAMMA2,SB1,SB2,GAMMA1)                   THE07710
C                                                                       THE07720
      COMPLEX *16  SM11(5,5),SM12(5,5),SM21(5,5),SM22(5,5),GAMMA2(30)   THE07730
      COMPLEX *16  H(30,30),CAPLAM(30),CAPOME(30),S11(30,30),S12(30,30) THE07740
      COMPLEX *16  YREG1(30,30),YREG2(30,30),S21(30,30),KA(30),HT(30,30)THE07750
      COMPLEX *16  S22(30,30),KD(30),KE(30),DEN(30,30),SB1(5),SB2(5)    THE07760
      COMPLEX *16  AA(30,30),AB(30,30),ALP,DEL,CT1(30),CT2(30),CT3(30)  THE07770
      COMPLEX *16  YINV1(30,30),YINV2(30,30),Y1(30),Y2(30),GAMMA1(30)   THE07780
      REAL *8 ALPHA,DELTA,A,D,ZT,WA(130),TEMP                           THE07790
      REAL TEMP1                                                        THE07800
      INTEGER NMODES,NMAX,IER,NPMODE,IM(5)                              THE07810
C                                                                       THE07820
      NMAX = 30                                                         THE07830
      DO 550 I = 1,NMODES                                               THE07840
          CT1(I)= ((D/2.0) + ((CDSIN(2.0*KA(I)*D))/(4*KA(I))))          THE07850
          CT2(I)= ((CDSIN(KD(I)*(A-D)))**2)                             THE07860
     8               /((CDCOS(KA(I)*D))**2)                             THE07870
          CT3(I)= (((A-D)/2.0)-((CDSIN(2.0*KD(I)*(A-D)))/(4*KD(I))))    THE07880
          CAPLAM(I) = 1.0D0/(CDSQRT(CT1(I) + CT3(I)/CT2(I)))            THE07890
          CAPOME(I) = 1.0D0/(CDSQRT((CT1(I)*CT2(I)) + CT3(I)))          THE07900
 550  CONTINUE                                                          THE07910
      ALPHA =((2.0/D)**0.5)                                             THE07920
      ALP = ALPHA                                                       THE07930
      DELTA = ((2.0/(A-D))**0.5)                                        THE07940
      DEL = DELTA                                                       THE07950
      DO 551 N = 1,NMODES                                               THE07960
         DO 552 M = 1,NPMODE                                            THE07970
            H(M,N) =  CAPOME(N) * DEL *                                 THE07980
     8    ((-1.0)**M)*(CDSIN(KD(N)*(A-D)))*(KE(M)/                      THE07990
     8    (KD(N)**2 - KE(M)**2))                                        THE08000
 552     CONTINUE                                                       THE08010
         NTEMP = NPMODE + 1                                             THE08020
         IF (NTEMP.GT.NMODES) GOTO 551                                  THE08030
         DO 555 MM = NTEMP,NMODES                                       THE08040
            H(MM,N) = CAPLAM(N) * ALP *                                 THE08050
     8    (((-1.0)**MM)*(CDCOS(KA(N)*D))*                               THE08060
     8     (KE(MM)/(KA(N)**2 - KE(MM)**2)))                             THE08070
 555     CONTINUE                                                       THE08080
 551  CONTINUE                                                          THE08090
      DO 553 I = 1,NMODES                                               THE08100
        DO 554 J = 1,NMODES                                             THE08110
          IF (I.NE.J) GOTO 563                                          THE08120
            YREG1(I,J) = Y1(I)                                          THE08130
            YREG2(I,J) = Y2(I)                                          THE08140
          GOTO 554                                                      THE08150
 563      YREG1(I,J) = (0.0,0.0)                                        THE08160
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          YREG2(I,J) = (0.0,0.0)                                        THE08170
 554    CONTINUE                                                        THE08180
 553  CONTINUE                                                          THE08190
      DO 571 I = 1,NMODES                                               THE08200
        DO 572 J = 1,NMODES                                             THE08210
          HT(I,J) = H(J,I)                                              THE08220
 572    CONTINUE                                                        THE08230
 571  CONTINUE                                                          THE08240
      CALL CMMUL (YREG1,HT,NMODES,AA)                                   THE08250
      CALL CMMUL (H,AA,NMODES,AB)                                       THE08260
      CALL CMSUM (YREG2,AB,NMODES,AA)                                   THE08270
      CALL CMSUB (YREG2,AB,NMODES,S22)                                  THE08280
      CALL LECTIC(AA,NMODES,NMAX,S22,NMODES,NMAX,0,WA,IER)              THE08290
      DO 580 I = 1,NMODES                                               THE08300
        DO 581 J = 1,NMODES                                             THE08310
          IF (I.NE.J) GOTO 582                                          THE08320
            DEN(I,J) = (1.0,0.0)                                        THE08330
          GOTO 581                                                      THE08340
 582      DEN(I,J) = (0.0,0.0)                                          THE08350
 581    CONTINUE                                                        THE08360
 580  CONTINUE                                                          THE08370
C                                                                       THE08380
C  DETERMINE MATRIX FOR PARAMETER S12                                   THE08390
C                                                                       THE08400
      CALL CMSUM (DEN,S22,NMODES,AA)                                    THE08410
      CALL CMMUL (HT,AA,NMODES,S12)                                     THE08420
C                                                                       THE08430
C  DETERMINE MATRIX FOR PARAMETER S21                                   THE08440
C                                                                       THE08450
      DO 5701 I = 1,NMODES                                              THE08460
         DO 5702 J = 1,NMODES                                           THE08470
            S21(I,J) = S12(J,I)*Y1(J)/Y2(I)                             THE08480
 5702    CONTINUE                                                       THE08490
 5701 CONTINUE                                                          THE08500
C                                                                       THE08510
C  DETERMINE MATRIX FOR PARAMETER S22                                   THE08520
C                                                                       THE08530
      CALL CMMUL (HT,S21,NMODES,AA)                                     THE08540
      CALL CMSUB (AA,DEN,NMODES,S11)                                    THE08550
C                                                                       THE08560
C  THIS COMPLETES THE S-MATRIX.  NOTE, EACH OF THE FOUR PARAMETERS      THE08570
C  ARE MATRICES IN THEMSELVES                                           THE08580
C                                                                       THE08590
      CALL PACMAN(GAMMA2,NPMODE,NMODES,IM)                              THE08600
      DO 540 I = 1,5                                                    THE08610
         DO 541 J = 1,5                                                 THE08620
            SM11(I,J) = S11(I,J)                                        THE08630
            SM12(I,J) = S12(I,IM(J))                                    THE08640
```

```
            SM21(I,J) = S21(IM(I),J)                                    THE08650
            SM22(I,J) = S22(IM(I),IM(J))                                THE08660
 541     CONTINUE                                                       THE08670
         SB1(I) = GAMMA1(I)                                             THE08680
         SB2(I) = GAMMA2(IM(I))                                         THE08690
 540  CONTINUE                                                          THE08700
C                                                                       THE08710
      RETURN                                                            THE08720
      END                                                               THE08730
C**SMATRI                                                                THE08740
C**CASCAD                                                                THE08750
      SUBROUTINE CASCAD(SM11,SM12,SM21,SM22,GAMMA1,GAMMA2,COSTWI,DIBECS,THE08760
     8                   NMODES,NSTRIP,ST11,ST12,ST21,ST22)             THE08770
C                                                                       THE08780
      COMPLEX *16 ST11(5,5),ST12(5,5),ST21(5,5),ST22(5,5)               THE08790
      COMPLEX *16 SS11(5,5),SS12(5,5),SS21(5,5),SS22(5,5)               THE08800
      COMPLEX *16 SM11(5,5),SM12(5,5),SM21(5,5),SM22(5,5)               THE08810
      COMPLEX *16 SD11(5,5),SD12(5,5),SD21(5,5),SD22(5,5)               THE08820
      COMPLEX *16 SE12(5,5),SE21(5,5),SE22(5,5)                         THE08830
      COMPLEX *16 GAMMA1(5),GAMMA2(5),TEMP,TEMP1                        THE08840
      REAL *8 COSTWI(20),DIBECS(19),AC,AR,AI,ATT                        THE08850
      REAL OUTPUT,AB                                                    THE08860
      INTEGER NMODES                                                    THE08870
C                                                                       THE08880
      DO 851 I=1,5                                                      THE08890
         DO 852 J=1,5                                                   THE08900
            ST11(I,J) = SM11(I,J)                                       THE08910
            SD11(I,J) = SM11(I,J)                                       THE08920
            ST12(I,J) = SM12(I,J)                                       THE08930
            SD12(I,J) = SM12(I,J)                                       THE08940
            ST21(I,J) = SM21(I,J)                                       THE08950
            SD21(I,J) = SM21(I,J)                                       THE08960
            ST22(I,J) = SM22(I,J)                                       THE08970
            SD22(I,J) = SM22(I,J)                                       THE08980
 852     CONTINUE                                                       THE08990
 851  CONTINUE                                                          THE09000
      TEMP1=SM11(1,1)                                                   THE09010
      AC = CDABS(TEMP1)                                                 THE09020
      NP = 5                                                            THE09030
      DO 861 II = 1,NSTRIP                                              THE09040
         CALL CASCA(ST11,ST21,ST12,ST22,SD22,SD12,SD21,SD11,NP,GAMMA2,  THE09050
     8               COSTWI(II),NP)                                     THE09060
      IF(II.EQ.NSTRIP) GOTO 861                                         THE09070
      DO 853 I=1,5                                                      THE09080
         DO 854 J=1,5                                                   THE09090
            SD11(I,J) = SM11(I,J)                                       THE09100
            SD12(I,J) = SM12(I,J)                                       THE09110
            SD21(I,J) = SM21(I,J)                                       THE09120
```

```
             SD22(I,J) = SM22(I,J)                                      THE09130
  854     CONTINUE                                                      THE09140
  853 CONTINUE                                                          THE09150
          CALL CASCA(ST11,ST21,ST12,ST22,SD11,SD21,SD12,SD22,NP,GAMMA1, THE09160
     8         DIBECS(II),NP)                                           THE09170
      DO 855 I=1,5                                                      THE09180
          DO 856 J=1,5                                                  THE09190
             SD11(I,J) = SM11(I,J)                                      THE09200
             SD12(I,J) = SM12(I,J)                                      THE09210
             SD21(I,J) = SM21(I,J)                                      THE09220
             SD22(I,J) = SM22(I,J)                                      THE09230
  856     CONTINUE                                                      THE09240
  855 CONTINUE                                                          THE09250
  861 CONTINUE                                                          THE09260
      RETURN                                                            THE09270
      END                                                               THE09280
C**CASCAD                                                               THE09290
C**TRANSM                                                               THE09300
      SUBROUTINE TRANSM(STE12,STE21,STE22,G,Z,N,X12,Y21,Z22)            THE09310
C                                                                       THE09320
      COMPLEX *16 STE12(5,5),STE21(5,5),STE22(5,5),X12(5,5)             THE09330
      COMPLEX *16 Y21(5,5),Z22(5,5),G(5),ZC,ZV(5)                       THE09340
      REAL *8 Z                                                         THE09350
      INTEGER N                                                         THE09360
C                                                                       THE09370
      ZC = Z                                                            THE09380
      DO 955 I = 1,N                                                    THE09390
        ZV(I) = CDEXP(-G(I)*ZC)                                         THE09400
  955 CONTINUE                                                          THE09410
      DO 950 J = 1,N                                                    THE09420
          DO 951 I = 1,N                                                THE09430
             X12(I,J) = ZV(I)*STE12(I,J)                                THE09440
             Y21(I,J) = STE21(I,J)*ZV(J)                                THE09450
             Z22(I,J) = ZV(I)*STE22(I,J)*ZV(J)                          THE09460
  951     CONTINUE                                                      THE09470
  950 CONTINUE                                                          THE09480
      RETURN                                                            THE09490
      END                                                               THE09500
C**TRANSM                                                               THE09510
C**DSUM                                                                 THE09520
      SUBROUTINE DSUM(SA11,SA12,SA21,SA22,SC11,SC12,SC21,SC22,MM,SE11,  THE09530
     8                SE12,SE21,SE22)                                   THE09540
C                                                                       THE09550
      COMPLEX *16 SA11(5,5),SA12(5,5),SA21(5,5),SA22(5,5)               THE09560
      COMPLEX *16 SC11(5,5),SC12(5,5),SC21(5,5),SC22(5,5)               THE09570
      COMPLEX *16 SE11(5,5),SE12(5,5),SE21(5,5),SE22(5,5)               THE09580
      COMPLEX *16 AA(5,5),AB(5,5),AC(5,5),DEN(5,5)                      THE09590
      REAL *8 ZT,WA(30)                                                 THE09600
```

```
      INTEGER MM,NMAX,IER                                               THE09610
C                                                                       THE09620
      DO 1050 I = 1,MM                                                  THE09630
         DO 1051 J = 1,MM                                               THE09640
            IF(I.NE.J) GOTO 1060                                        THE09650
            DEN(I,J) = (1.0,0.0)                                        THE09660
            GOTO 1051                                                   THE09670
 1060       DEN(I,J) = (0.0,0.0)                                        THE09680
 1051    CONTINUE                                                       THE09690
 1050 CONTINUE                                                          THE09700
      NMAX = 5                                                          THE09710
C                                                                       THE09720
C FIRST TO DEVELOP THE SE12 MATRIX                                      THE09730
C                                                                       THE09740
      CALL CMMUL( SC11,SA22,MM,AA)                                      THE09750
      CALL CMSUB(DEN,AA,MM,AB)                                          THE09760
      CALL CMMUL( SC11,SA21,MM,AA)                                      THE09770
      CALL LECT1C(AB,MM,NMAX,AA,MM,NMAX,0,WA,IER)                       THE09780
      CALL CMMUL( SA12,AA,MM,AC)                                        THE09790
      CALL CMSUM( SA11,AC,MM,SE11)                                      THE09800
C                                                                       THE09810
C NOW TO DEVELOP SE12                                                   THE09820
C                                                                       THE09830
      ZT = 1.0                                                          THE09840
      CALL CMRNMU (SC12,ZT,MM,AA)                                       THE09850
      CALL LEQT1C (AB,MM,NMAX,AA,MM,NMAX,2,WA,IER)                      THE09860
      CALL CMMUL( SA12,AA,MM,SE12)                                      THE09870
C                                                                       THE09880
C NOW TO DEVELOP SE21                                                   THE09890
C                                                                       THE09900
      CALL CMMUL( SA22,SC11,MM,AA)                                      THE09910
      CALL CMSUB(DEN,AA,MM,AB)                                          THE09920
      CALL CMRNMU(SA12,ZT,MM,AA)                                        THE09930
      CALL LECT1C(AB,MM,NMAX,AA,MM,NMAX,0,WA,IER)                       THE09940
      CALL CMMUL( SC21,AA,MM,SE21)                                      THE09950
C                                                                       THE09960
C NOW TO DEVELOP SE22                                                   THE09970
C                                                                       THE09980
      CALL CMMUL( SA22,SC12,MM,AA)                                      THE09990
      CALL LEQT1C(AB,MM,NMAX,AA,MM,NMAX,2,WA,IER)                       THE10000
      CALL CMMUL( SC21,AA,MM,AB)                                        THE10010
      CALL CMSUM(AB,SA22,MM,SE22)                                       THE10020
      RETURN                                                            THE10030
      END                                                               THE10040
C**DSUM                                                                 THE10050
```

APPENDIX G

SAMPLE CAD OUTPUT TO CRT

```
ENTER 1 IF YOU WANT THE COMPUTER TO DESIGN AND TEST
A FILTER FOR YOU OR "0" IF YOU WANT TO ENTER YOUR OWN DESIGN.
THIS IS A PROGRAM USED TO DESIGN FILTERS.
YOU WILL BE PROMPTED FOR THE REQUIRED INPUTS.
ENTER THE FILTER NUMBER FOR YOUR GRAPH.
       7

INPUT HALF OF THE WAVE GUIDE WIDTH
AND DISTANCE FROM THE CENTER OF THE GUIDE TO SEPTUM EDGE.
       1.14300000       0.00200000

INPUT THE COEFFICIENTS FOR THE DIELECTRIC BETWEEN
FIRST THE CENTER OF THE GUIDE AND SEPTUM EDGE;
AND SECOND BETWEEN SEPTUM WALL AND WAVEGUIDE WALL
       1.00000000       1.00000000

NOW YOU WILL INPUT THE FILTER PARAMETERS
ENTER THE BEGINNING AND END FREQUENCY FOR THE PASSBAND
OF THE FILTER.
       8.40000000       8.80000000

NOW ENTER THE FREQUENCY AND DB DOWN FOR THE
TAIL OF THE FILTER
       9.00000000      25.00000000

NOW ENTER THE RIPPLE IN DB ON THE TOP OF THE PASSBAND.
       0.15000000

THE FINAL OUTPUT OF THIS PROGRAM IS A GRAPH.
ENTER THE BEGINNING POINT OF THE GRAPH IN GHZ
       7.80000000

ENTER THE FREQUENCY INTERVAL IN MHZ AND
THE NUMBER OF STEPS THAT YOU WOULD LIKE
      20.00000000      101

ENTER THE INTERVAL MARKS FOR THE GRAPH
AND THE END POINT FOR THE GRAPH.
       0.20000000       9.80000000

ENTER THE YAXIS ZERO POINT AND TICK MARK INTERVALS
FOR THE GRAPH IN DB.
     -30.00000000      10.00000000

ENTER THE YAXIS HIGH POINT IN DB.
       0.0

 CENTER FREQUENCY IS    8.5875
```

```
 SD = 0.0     RH = 0.187D+00  N =  6

HERE IS THE S11(I) ELEMENTS
  0.73588D+00-0.95755D+00 0.97438D+00-0.97620D+00 0.97438D+00-0.95755D+00
  0.73588D+00

HERE ARE THE   7 CONDUCTING STRIP WIDTHS
AND THE   6 RESONATOR WIDTHS

     0.09060973      2.04797381
     0.47936749      2.12270522
     0.59607291      2.12795985
     0.61337277      2.12795985
     0.59607291      2.12270522
     0.47936749      2.04797381
     0.09060973

LISTED BELOW IS THE POWER TRANSMITTED THRU YOUR
FILTER FOR EACH RESPECTIVE FREQUENCY POINT.

DB LOSS, FREQ IN GHZ, ENERGY CHECK   -98.016602      7.8000    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -96.233795      7.8200    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -94.411285      7.8400    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -92.546646      7.8600    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -90.637238      7.8800    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -88.660145      7.9000    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -86.672180      7.9200    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -84.609802      7.9400    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -82.489044      7.9600    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -80.305496      7.9800    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -78.054214      8.0000    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -75.729599      8.0200    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -73.325287      8.0400    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -70.833969      8.0600    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -68.247253      8.0800    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -65.555344      8.1000    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -62.746765      8.1200    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -59.807846      8.1400    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -56.722168      8.1600    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -53.469696      8.1800    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -50.025482      8.2000    1.0000
```

```
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -46.357971      8.2200    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -42.426056      8.2400    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -38.174652      8.2600    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -33.527115      8.2800    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -28.371704      8.3000    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -22.537704      8.3200    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -15.764248      8.3400    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -7.856019      8.3600    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -1.104898      8.3800    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -0.011268      8.4000    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -0.050644      8.4200    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -0.000850      8.4400    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -0.076754      8.4600    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -0.135845      8.4800    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -0.086494      8.5000    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -0.011467      8.5200    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -0.012955      8.5400    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -0.085820      8.5600    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -0.145542      8.5800    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -0.131783      8.6000    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -0.061411      8.6200    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -0.004745      8.6400    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -0.015078      8.6600    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -0.073450      8.6800    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -0.109286      8.7000    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -0.077027      8.7200    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -0.013639      8.7400    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -0.010848      8.7600    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -0.080297      8.7800    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -0.070596      8.8000    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -0.028788      8.8200    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -1.449127      8.8400    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK    -5.840528      8.8600    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -11.100730      8.8800    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -15.888702      8.9000    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -20.082428      8.9200    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -23.781113      8.9400    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -27.083817      8.9600    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -30.065781      8.9800    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -32.782669      9.0000    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -35.276154      9.0200    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -37.578247      9.0400    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -39.714066      9.0600    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -41.703720      9.0800    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -43.563568      9.1000    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -45.307175      9.1200    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -46.945923      9.1400    1.0000
DB LOSS, FREQ IN GHZ, ENERGY CHECK   -48.489426      9.1600    1.0000
```

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DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -49.945969          9.1800     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -51.322678          9.2000     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -52.625748          9.2200     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -53.860672          9.2400     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -55.032227          9.2600     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -56.144714          9.2800     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -57.201920          9.3000     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -58.207291          9.3200     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -59.163879          9.3400     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -60.074478          9.3600     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -60.941605          9.3800     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -61.767563          9.4000     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -62.554428          9.4200     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -63.304123          9.4400     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -64.018417          9.4600     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -64.698914          9.4800     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -65.347122          9.5000     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -65.964417          9.5200     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -66.552063          9.5400     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -67.111252          9.5600     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -67.643066          9.5800     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -68.148560          9.6000     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -68.628662          9.6200     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -69.084259          9.6400     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -69.516205          9.6600     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -69.925262          9.6800     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -70.312149          9.7000     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -70.677582          9.7200     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -71.022156          9.7400     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -71.346512          9.7600     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -71.651184          9.7800     1.0000
DB  LOSS, FREQ  IN  GHZ, ENERGY CHECK    -71.936722          9.8000     1.0000
```

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